AD NUMBER	
AD507578	
CLASSIFICATION CHANGES	
TO:	unclassified
FROM:	confidential
LIMITATION CHANGES	
TO:	Approved for public release, distribution unlimited
FROM:	Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 26 JAN 1965. Other requests shall be referred to Office of Naval Research, Arlington, VA 22203.
AUTHORITY	
ONR ltr, 8 Oct 1975; ONR ltr, 8 Oct 1975	

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OPEN-OCEAN ASW AIR-SEA CRAFT SYSTEM FEASIBILITY STUDY (U)

VOLUME V

AIR-SEA CRAFT OPEN-OCEAN CAPABILITIES, CANDIDATE SYSTEMS, AND COST FACTORS

Prepared For:
DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
AIR PROGRAMS

CONTRACT NO. Nonr 4545(00)
CAL REPORT NO. GM-1968-G-1
26 JANUARY 1965

CORNELL AERONAUTICAL LABORATORY, INC.
OF CORNELL UNIVERSITY, BUFFALO, N. Y. 14221

CONFIDENTIAL

CORNELL AERONAUTICAL LABORATORY, INC./CM-1968-G-1, Vol 5.
BUFFALO, NEW YORK 14221

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ABSTRACT

The Cornell Aeronautical Laboratory's open-ocean ASW air-sea craft system feasibility study final report has been prepared in six volumes. This volume presents an analysis of ASW air-sea craft open-ocean capabilities (Part I), a summary of candidate ASW air-sea craft vehicle-acoustic sensor systems (Part II), and ASW air-sea craft system cost factors (Part III). Part I presents the results of five brief analyses in an attempt to determine the limits of the capabilities of and problems associated with proposed types of air-sea craft vehicles in open-ocean takeoff, landing, and sea-sitting operations. Part II presents the characteristics of the potential candidate air-sea craft - acoustic sensor combinations and the rationale used in the selection, from the potential candidate systems of a limited number of air-sea craft systems for cost-effectiveness analyses. Part III presents a methodology for determining air-sea craft system cost factors, including numerical values for the various costs. The results of the studies in Parts II and III are utilized in Volume VI of this Report to evaluate the cost-effectiveness of air-sea craft operating in selected ASW missions.

PREFACE

Volume V of this report on Project ASWAIRS (ASW Air-Sea Craft Study) has been prepared by the Cornell Aeronautical Laboratory, Inc. to document part of the work that has been accomplished under Contract No. Nonr 4545(000). This study was made for the Department of the Navy, Office of Naval Research, Air Programs. Originally, the period of the contract spanned seven months, beginning on May 15, 1964 and ending on December 15, 1964. An extension from December 15, 1964 to January 26, 1965 was obtained from the Office of Naval Research to allow for completion of unfinished portions of the work and review and publication of the final reports.

The objective of this study as defined in the contract is "to conduct studies and analysis of the technical feasibility and evaluation of detailed technical designs of an open-ocean air-sea craft weapon system for ASW operations." The program consists of six major study phases which are designed to achieve this objective. These study phases are:

Phase I: Determine the ASW threat for the 1973-1980 time period on the basis of currently available information.

Phase II: Assess the technical feasibility of submitted ASW air-sea craft systems.

Phase III: Establish system cost factors and assign cost estimates to subsystem elements.

Phase IV: Determine candidate ASW air-sea craft system comparative worth.

Phase V: Determine candidate ASW air-sea craft systems cost-effectiveness in performing selected ASW missions.

Phase VI: Define critical technial problem areas that require solution prior to undertaking development of an air-sea craft weapon system.

Besides Volume V, the open-ocean ASW air-sea craft system feasibility study Final Report GM-1968-G-1 consists of five additional volumes. These are listed as follows:

Volume I	Study Summary, Conclusions, and Critical Technical Problem Areas
Volume II	Estimated Submarine Threat 1973-1980
Volume III	Air-Sea Craft Operational Sea Environment
Volume IV	Air-Sea Craft and Acoustic Sensor System Characteristics, Performance, and Technical Feasibility.
Volume VI	Air-Sea Craft Systems Cost-Effectiveness in ASW Missions

The guidance, technical assistance and suggestions provided by Mr. F. W. Locke Jr. of the Bureau of Naval Weapons concerning Part I and Part III of this volume of the report is greatly appreciated. The following Cornell Aeronautical Laboratory personnel contributed to the work upon which this volume of the report is based:

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1.0 STUDY INTRODUCTION

1.1 Principal Open-Ocean ASW Air-Sea Craft System Feasibility Study Objectives

The U. S. Navy has indicated that (1) the seriousness of the future submarine threat warrants an intensive search for naval vehicle-sensor system combinations that will provide the most effective ASW counteraction, (2) considerable effort is being expended to increase the mobility and speed advantages of surface craft to conduct ASW operations, and (3) the current and projected state-of-the-art in ASW seaplanes and sensors has suggested the possibility of an aircraft which is designed specifically to cope with the ASW threat on the open ocean. Thus, on a technical feasibility basis, the question arises as to whether an ASW air-sea craft-sensor system can be designed which combines the mobility, flexibility, range, and search capabilities of aircraft with the detection, identification, persistence, and kill capabilities of water-borne craft. In facing this problem, the overall objectives of the ASW air-sea craft system feasibility study are to:

1. Evaluate the current and predictable future ability to develop an open-ocean air-sea craft system which is capable of airborne ocean ASW surveillance and of landing, taking off, and operating usefully on the water

2. Determine the most promising vehicle-sensor combinations, and analyze, determine, and project technical feasibility, system effectiveness, and comparative costs for possible operational employment in 1973-1980.

1.2 Study Approach

The objectives of the part of the study contained in this volume are to (1) determine the limits of the capabilities of and problems associated with proposed types of air-sea craft vehicles in open-ocean takeoff, landing, and sea-sitting ASW operations in the expected sea environment, (2) select candidate air-sea craft vehicles and acoustic sensor systems from the aggregate of potential systems summarized in Volume IV of this report; these selected systems are to be used in the cost-effectiveness studies of air-sea craft systems in selected ASW missions (Volume VI), and (3) determine the cost factors to be utilized in the aforementioned cost-effectiveness studies. This volume of the report is divided into three parts. Part I presents analyses of air-sea craft open-ocean capabilities. Part II presents a selection of candidate air-sea craft vehicles and acoustic sensors. Part III presents air-sea craft and sensor system cost factors.

Although the desired quantitative results could not be obtained in an effort to determine the limiting capabilities of various types of air-sea craft in takeoff, landing, and sea-sitting operations, several analyses are presented which should be helpful in defining the required research program to obtain this information.

The procedure followed in determining candidate air-sea craft systems is based on ASW mission analyses which determined the capabilities required of these systems in carrying out each mission. These requirements were then matched as closely as possible with candidate systems capabilities in the list of potential candidate systems.

Accepted U.S. Navy procedures were followed in determining air-sea craft vehicle and acoustic sensor system cost factors. A cost methodology has been developed which includes initial, operating, fuel, maintenance, personnel, system, procurement, mission and additional operating costs and system utilization factors.

1.0 INTRODUCTION

1.1 Study Objectives

There are two basic objectives toward which this portion of the air-sea craft study is directed:

1) Evaluation of the relative open-ocean operational feasibility of the different air-sea craft configuration or conceptual types.

2) Delineation of the extent to which the sea environment may limit candidate air-sea craft operations

Factors bearing on operational feasibility include landings, take-offs and surface sea-keeping performance with respect to both ASW mission sensor operations and human factor thresholds of efficiency and endurance. Industry-supplied portions to this project were to serve as input points defining the landing and take-off limits of their specific submitted designs in response to the ONR mission inquiries. These industry responses resorted to unsupported sea-state capability statements in all instances (except one), thus obviating any realistic assessment of potential roughness constraints. Several designs were obviously past studies which were generated to meet other payload and performance criteria. Only summarized gross data were presented, precluding the possible extension of analyses of these configurations to permit an approximate confirmation of the claims.

The task of estimating operational feasibility was therefore reoriented toward sea-air interface performance calculations to fill the input gaps existing in the submitted design information. The analysis, which follows, consists of a rapid evaluation of existing state-of-the-art capability in full-scale operational experience, followed by an extrapolation of results of model tests of dynamically similar conventional type air-sea craft, i.e. conventional take-off and landing types (CTOL) and short take-off and landing types (STOL). Only a limited success was achieved in qualitative assessments since the wave heights of interest are half an order of magnitude greater than those for which test data are available.

2.0 SUMMARY

Four study tasks have been performed in an attempt to analyze and determine the limits of the capabilities of and the problems associated with several proposed types of air-sea craft in open-ocean takeoff, landing and sea-sitting ASW operations in the expected sea environment. A number of obstacles were encountered which prohibited the two critical study objectives from being attained on a quantitative basis. These obstacles are discussed in detail in Subsections 5.1 through 5.6, Part I of this volume of the report, in which the results of the various study tasks are presented. The four tasks are summarized as follows:

1. From literature and reports available to this study, review, tabulate, and summarize the pertinent results of past experience with and tests of contemporary seaplanes in open-ocean takeoff and landing operations.

2. Perform an analysis and determine the problems associated with open-ocean takeoffs of CTOL- and STOL-type air-sea craft operating in various sea states.

3. Determine pitch and roll control requirements for VTOL type air-sea craft equipped with sea legs in open-ocean takeoff and landing operations in a 35-knot wind and its associated wave motion.

4. Perform an analysis of the open-ocean landing capability of CTOL- and STOL-type air-sea craft for the annual average wave height versus wind velocity in the worst weather sector of the Argentia-Azores ASW barrier.

Referring to Study Task 1, the results of a series of controlled tests on a PBM-3 aircraft conducted by the U.S. Coast Guard are summarized in Subsection 5.2. One of the objectives of these tests was to determine landing and takeoff capability limits at various angles with respect to wind direction and wave motion in wave heights up to 11 feet and associated winds up to 39 knots. Also presented is a summary of present limitations and problems in towing scale models in tanks to determine seaplane takeoff and landing capability in high waves. A number of conclusions are drawn based on the presented results.

The principal objective in Study Task 2, which is presented in Subsection 5.3, has been to determine takeoff resistance of generic CTOL- and STOL-type seaplanes as a function of increasing wave height. The results form a basis which can be used in specifying required air-sea craft thrust levels during takeoff as a function of takeoff distance and time. In addition, quantification of the takeoff properties of this generic family of seaplanes has been attempted in order to determine the degree of sensitivity of resistance with increasing wave height and whether a threshold in sea state exists beyond which seaplanes cannot operate.

In Study Task 3, a preliminary analysis has been conducted (Subsection 5.4) of pitch and roll control requirements for VTOL-type air-sea craft which employ sea legs in open-ocean takeoff and landings. The pitch and roll control moment requirements are examined for a typical VTOL-type configuration when exposed to a 35-knot wind and for an asymmetrical dunking of the sea legs in waves. The results of this study indicate that flight control requirements appear to be an important new consideration in landing and takeoff operations when employing these type vehicles.

A brief analysis of the open-ocean landing capability of CTOL- and STOL-type air-sea craft has been conducted in Study Task 4 and is summarized in Subsection 5.5. Included in the results of the landing impact load factor analysis are:

1. Maximum wave heights as a function of wind velocity which are determined on an annual average basis for the worst weather sector of the Argentia-Azores barrier.
2. Landing impact load factor versus air-sea craft weight as a function of landing speed for the specified wave characteristics, landing speed versus weight as a function of load factor, and load factor versus wave height as a function of landing speed.
3. The effect of wind on landing impact load factor and maximum landing airspeed as a function of wave height.

3.0 CONCLUSIONS

1. Present aircraft design knowledge is not adequate to predict with assurance the operating capability of air-sea craft in high (5-7) sea states (Section 5.3 of Part I).

2. Experienced and proficient pilots can operate 40,000 to 50,000 lbs. gross weight CTOL-type flying boats of the PBM-3 class with no hydroski in sea states 3 to 5. Frequent damage to the aircraft occurs above sea state 4 (Section 5.2 of Part I).

3. Full-scale flight tests indicate that repeatable success is achievable in sea state 3 (5 - 8 feet waves), limited success in sea state 4 and poor success in sea state 5 conditions (Table 1 and Figure 1).

4. Achievement of very low takeoff and landing speeds will alleviate the rough-sea operating problems. Thus, emphasis on the application of high-lift devices, lift spoiling and water drag devices, and augmented low-speed latitude control systems may be expected to pay off (Figures 12, 14 and 16).

5. The nonlinear characteristics of the takeoff resistance parameters in smooth water to wave heights of 6 feet prohibit extrapolation to higher sea state (Figures 2, 3, 4 and 6).

6. Much higher thrust-weight ratios will be required when operating in 16-foot waves than in 5 - 8 foot waves. Thus, the use of auxiliary propulsion systems such as rockets may be mandatory (Figure 2 and 6).

7. STOL seaplanes will have substantially increased and improved sea state operating capability and safety in comparison with conventional seaplanes, such as the P5M or P6M types, because of slower flying speeds at liftoff and touchdown (e.g., 50-70 knots). For those types of seaplanes that are not capable of slow flight, the addition of a hydroski will reduce wave impact loads on the hull in the higher speed regimes of the takeoff and

landing maneuvers. The size of the air-sea craft will also be an important consideration in determining sea state capability because the ratios of size to wave length and height are reduced. The addition of boundary layer control (BLC) or slipstream control to provide positive roll control at low speeds will be a necessity for safety and improvement in landing and takeoff operations (Sections 5.5.1 and 5.5.2 of Part I).

8. For a 75,000-pound seaplane landing into the minimum wind at 75 knots airspeed, the load factor remains essentially constant for increasing wave heights. In an average wind, the load factor reduces for increasing wave heights. In zero wind, the load factor rapidly increases (Figure 15).

9. The landing airspeeds for seaplanes designed to withstand a 3g initial impact load factor must be kept significantly lower than for those designed to 4 or 5 g load factors (Figure 16).

10. Assuming a 5 g design load factor, maximum wave height landing capability into a minimum wind and maximum wave slope increases from 7 feet at 75 knots airspeed to 22 feet at 45 knots airspeed for a seaplane landing weight of 25,000 pounds. Similarly, these respective values increase from 23 feet to greater than 30 feet for a seaplane landing weight of 300,000 pounds (Figure 16).

11. Sea legs offer considerable promise for improving sea-keeping capabilities. Further investigation is required in order to produce meaningful design information, such as aerodynamic and hydrodynamic loads, structural material, and attachment and storage configurations. For those designs wherein the major function of sea legs is motion damping (not prime floatation), there may be better solutions; search for these should continue. No analyses have been conducted in this study and insufficient information is available at the present time to determine operational trade-offs involved in the employment of sea legs (Sections 5.3 and 5.4 of Part I).

12. Flight control requirements are an important new consideration for VTOL-type air-sea craft with sea legs when operating in the expected environment (Section 5.4 of Part I).

13. Air drag on the deployed sea legs in a 35-knot wind for the typical VTOL analyzed increases control requirements by 82% in roll and only 4% in pitch (Section 5.4 of Part I).

14. For VTOL air-sea craft landing with sea legs deployed, severe upsetting moments may be encountered due to asymmetrical dunking of the sea legs. These moments are estimated to require an increase in control power, over that required for normal operations, of the order of 144 percent (Section 5.4 of Part I).

4.0 RECOMMENDATIONS

1. It is necessary to determine an analytical method capable of accurately predicting air-sea craft takeoff and landing parameters in varying degrees of sea surface roughness, and to substantiate this method by tests. The effects of surface wind and landing and takeoff runs diagonal or normal to the wave pattern should be included.

2. Dynamic analyses, model, and full-scale tests are required to determine the motions of conventional hull-type, and VTOL-, STOL- and CTOL-type candidate air-sea craft equipped with sea legs in the expected maximum rough sea environments.

3. Detailed analyses, model, and full-scale tests of the flight control capabilities of VTOL-type air-sea craft equipped with sea legs are required because substantial upsetting moments on the deployed sea legs caused by large wave motion and winds may be present during landing and takeoff operations.

4. An evaluation of the effects of sea spray on air-sea craft flaps, control surfaces and water ingestion by engines is necessary. The degree of rough water tests is anticipated to be well beyond recent past practice.

5. A comprehensive study of thrust requirements for take-off, landing, and sea-sitting operations in increasing wave heights must be conducted. These studies include (1) the use of auxiliary high-thrust assist for infrequent conditions (2) the benefits of thrust drag brake devices in landing operations and (3) thrust control methods to enhance sea surface maneuverability.

6. A test program in basic rough water hydrodynamics is necessary to provide the information that is required to solve some of the rough sea effects problems.

5.0 ANALYSIS OF AIR-SEA CRAFT CAPABILITY IN OPEN-OCEAN TAKEOFF, LANDING, AND SEA-KEEPING OPERATIONS

5.1 Introduction

Compatibility of the Air-sea craft vehicles with the sea environment is one of the key requirements for the efficient execution of ASW missions. Since the submarine is immune to sea-surface conditions when submerged, an ASW defense system must maintain a very high on-station time in spite of adverse environmental conditions. There is no existing defense system, other than SSK submarines, which can assure a 100 percent time-on-station operational capability regardless of sea conditions. Air-sea craft, therefore, which have particular potential advantages over other defense systems, such as very high search rates, do not have to offer a 100 percent time-on-station capability to be competitive. However the limits of their capability and those of their competitors must be known if defensible comparative evaluations are to be made.

The frequency of occurrence of given wave heights and sea states is fairly well documented. The problem, therefore, is to determine the limitations imposed by waves of various heights, up to the maximum expected, on the performance of ASW missions by the various types, configurations, and sizes of air-sea craft. Equally important is the degree of accuracy and hence confidence to which this limit can be determined. Since the expected differences in operational sea roughness limit between competing air-sea craft concepts may be small, the determination methods utilized must provide valid and defendable values of limiting operational wave heights and wave lengths.

A total of 29 designs of contemporary aircraft and proposed air-sea craft ranging from conventional seaplanes to ducted propeller vertical takeoff types have been summarized in Part I of Volume IV. Of these, 18 designs were submitted by industry in response to a request by the Office of Naval Research. The latter were generated specifically to satisfy the four ASW mission profiles proposed by the Navy. Obviously, no single design could be formulated in sufficient detail to permit estimation of small differences in performance which can be expected due to small changes of sea state. As a result, the analysis and conclusions presented herein indicate trends rather than exact characteristics.

All of the postulated configurations may be classified as belonging to one of two flight types. The first type requires a horizontal component of velocity for takeoff and landing on the sea surface. The second type requires only a vertical component of motion for takeoff and landing operations. A further subdivision of these types is based on their means of sea-keeping buoyancy. Again, there are two general classifications: those having hulls and those employing sea legs. Analyses have been made of the pertinent data available to this study concerning the sea-keeping characteristics of air-sea craft configurations which are representative of the two flight types employing appropriate means to obtain desired buoyancy.

5.2 Summary of Open-Ocean Landing and Takeoff Capability of Contemporary Seaplanes

Open-ocean operational experience is essentially confined to an "emergency" status rather than by design or intent. The U.S. Coast Guard has conducted open-ocean tests (Reference 1) to evaluate landing and takeoff piloting techniques. These tests are well documented and include wave heights and wind speed measurements made from a reliable surface reference point. Table 1 summarizes the data for PBM-3 flying boats extracted from the cited tests. These data are superimposed on a sea state summary chart as shown on Figure 1. Solid square symbols indicate those landings resulting in aircraft damage. All pilots were experienced and proficient in open-ocean piloting techniques. Since wave height is the predominant constraint on operations, Figure 1 indicates that experienced pilots can operate PBM-3 aircraft in sea states 3 to 5. Frequent damage occurs commencing at sea state 4. These data are representative of the capabilities of a typical non-hydroski-equipped 43,000-pound flying boat of the 1944-50 era, where prescheduled tests were conducted. There have been numerous emergency landings of transport flying boats in very rough seas; these are recognized as evidence of achievable performance but do not furnish usable operational research data.

TABLE 1

SUMMARY OF OPEN-SEA PBM-3 LANDING AND TAKEOFF TESTS

Date (1944-45)	Swell Dir Speed and Height	Wind Dir 8 & Velocity	Gross Weight	C of G % MAC	Pilot	Co-Pilot	Place	Number of Landings	Number of Jet Assist Take-offs
17 Nov	W 5 kn 8'	NW 5 kn	42300	28.8	MacDiarmid	Wall	Pt. Loma	2	
18 Nov	W15 kn 10'	W 10 kn	43000	30.1	"	Weed	"	3	
19 Nov	W15 kn 11'	W 10 kn	43000	30.1	"	Sutton	"	3	
24 Nov	W 20 kn 8'	W 5 kn	43000	30.0	Weed	MacDiarmid	"	2	
25 Nov	W 30kn 3'	W 10 kn	43200	30.1	MacDiarmid	Gould	"	1	1
28 Nov	W 30kn 3'	W 5 kn	43000	30.0	Weed	Davis	"	4	
1 Dec	W20 kn 6'	W 14 kn	43200	30.3	Weed	Naoteboon	Pt. Loma	3	3
2 Dec	W25/8'sea/ 3' swell	W 15 kn	43000	31.9	MacDiarmid	Weed	"	2 *	1
11 Dec	W25 kn 5'	W 5 kn	43500	31.0	"	Gould	"	1	1
12 Dec	W10 kn 1'	Calm	43800	30.0	"	Bender	SanClemente	7	4
14 Dec	W25/48 kn 6'/4'	E 5 kn	43300	31.5	"	Gould	Pt Arguello	5 *	1
6 Jan	W19 kn 7'	W 4 kn	43400	30.8	MacDiarmid	Davis	Santa Cruz	2 *	
12 Jan	7' Sea NxW swell 30 kn 6'	NXW 18 kn	42100	30.0	"	Vukie	500 mi W/ SanDiego	1	1
20 Jan	NW24 kn10'	NNW 16 kn	44000	30.6	"	McMullan	Pt. Loma	1 *	
30 Jan	W39 kn 3'	W 5 kn	43800	31.5	"	"	Pt. Loma	4	
6 Feb	NW39 kn 5'	NW 15 kn	44000	30.1	McMullan	MacDiarmid	Pt. Loma	2	1
9 Feb	WNW24 kn 8'	W 20 kn	43000	29.6	Davis	"	Pt. Loma	1	
10 Feb	W30 kn 4'	W 7 kn	43200	29.9	MacDiarmid	Davis	Pt. Loma	5	1
15 Feb	WNW 15 kn 6'	W 7 kn	44500	30.6	"	Turboy & Storm	Pt. Loma	3	
20 Feb	W30 kn 5'	Calm	43000	30.8	Davis	DeJoy & Harris	Pt. Loma	2	1
							TOTALS	54	15

* Plane was damaged

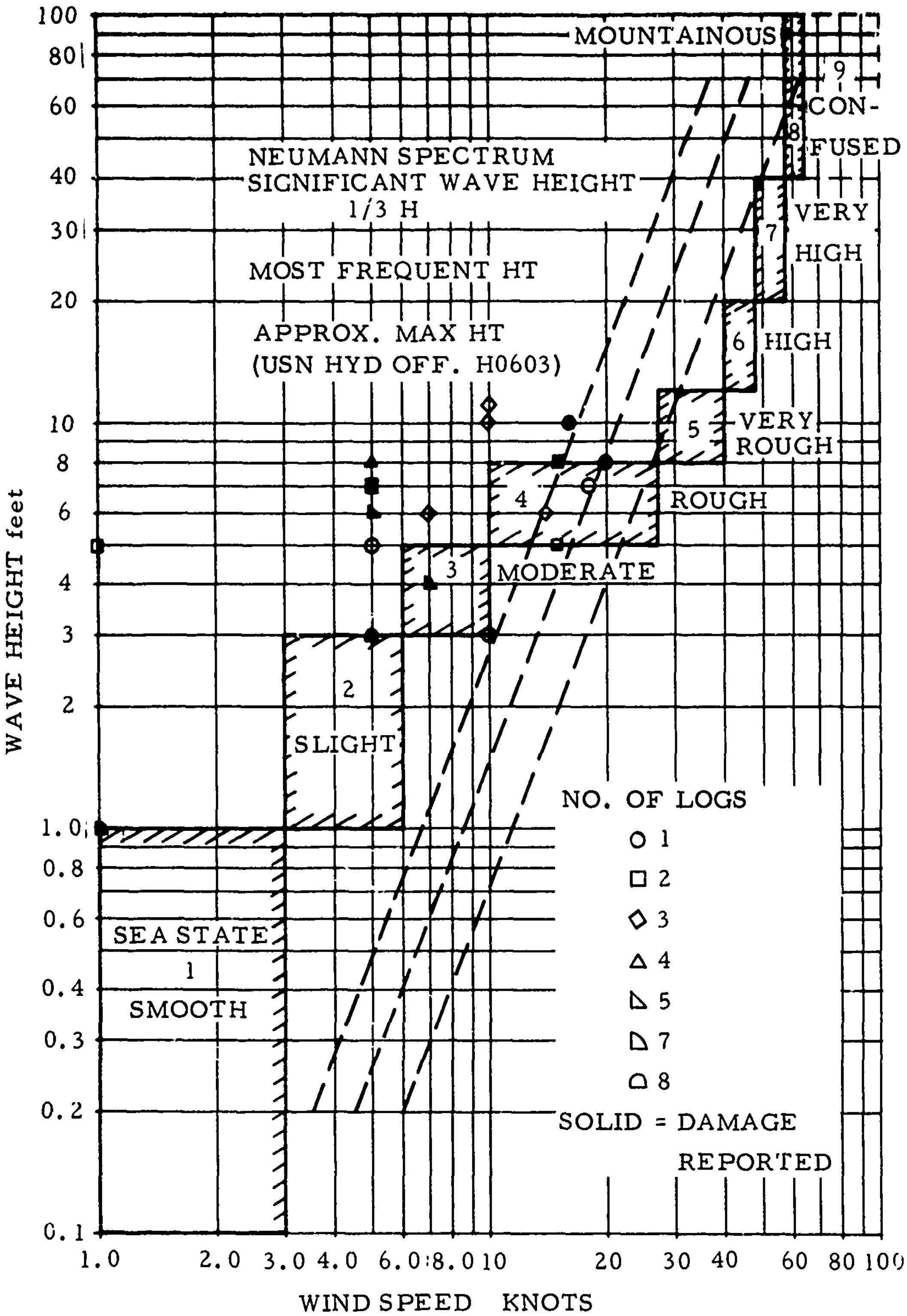

Figure 1 SUMMARY OF PBM-3 TESTS

In summary, full-scale flight tests indicate a repeatable successful performance in sea state 3 (5-8 ft. waves), limited success in sea state 4, and sparse success in sea state 5. The tests are indicative of the performance of 40 to 50,000-pound gross weight conventional takeoff and landing flying boats without hydroski.

The following characteristics are listed for the PBM-3 flying boat:

Take-off gross weight (TOGW)	=	45,000 pounds
Initial waterborne coefficient C_{Δ_o}	=	.77
Wing loading (at test Wt.), W/S	=	31 psf
Stall speed (indicated V_{STL})	=	60 to 70 knots
Maximum static thrust (est.), F_s	=	8500 lbs
JATO (2) Thrust	=	2000 lbs
Duration		14 sec
Hull length-to-beam ratio, L/b	=	6
Hull deadrise angle at step, β	=	20 degrees

Larger and more modern seaplanes will undoubtedly provide better rough-water capability if designed to specific mission requirements. Greater length-to-beam ratios and higher dead rise angles will alleviate the impact accelerations if landing speeds are not allowed to increase as well. However, in attempting to remain competitive with land-based planes, designers have allowed wing loads on some seaplanes to increase substantially. As a consequence, rough-water takeoff, landing, and sea-keeping performance has been considered an emergency operation with normal landings and takeoffs limited to sheltered waters. If an ASW air-sea craft is specifically designed for rough-water operation, it is possible that an increase in capability of two sea states could be achieved over that of the PBM-3 Seaplane. This implies successful operations in sea state 5 and possibly 6 which is equivalent to wave heights of 10 to 20 feet. The takeoff performance from this sea surface will require much higher thrust-to-weight ratios because of the added resistance caused by increased wave impacts and hull wetting. In order to circumvent the porpoising problem inherent at the higher speeds and low allowable trim angles, the air-sea craft must take off at relatively low speed. Thus, an analysis was initiated to examine the thrust-to-weight requirements. The available data were limited to low wave heights and aircraft configurations which were not intended to exploit rough-water performance capability.

An attempt has been made in this study to generate analytical techniques for assessing the effects of sea state on air-sea craft operation. The following discussion reviews the state-of-the-art on rough-water performance of seaplanes for the degrees of roughness that are considered to be representative of recent, past, and current operation.

All take-off, landing, and sea-keeping operations imply the need to evaluate the dynamic behavior of the air-sea craft. Dynamic analysis or tests require detailed knowledge of the vehicle regarding the mass distribution, geometric proportions, restoring forces or moments, and damping. This detailed knowledge implies that specific designs have been subjected to detailed analysis. In order to draw conclusions on designs which depart from a specific design, a large number of analyses are necessary in order to establish the limiting trends of the vehicle under consideration. Obviously, this implies an effort which is beyond the scope of the study. Furthermore, this level of detail is believed to be unjustified until it has been proven that the ASW mission performance of air-sea craft, neglecting sea constraints, is attractive or competitive with other ASW defense systems or concepts.

Dynamically similar models have been used exclusively for engineering evaluation of seaplane designs. Landing and take-off tests have been performed in tow tanks. The behavior of seaplane models in waves has been examined in the same manner but has heretofore been limited by the size wave which can be simulated in tanks. These have generally been limited to about 6 feet* reflected to full size for the model sizes suitable for test. Even so, many tests were curtailed because of hazards on the model or instrumentation

*The Langley tanks (NASA) and Davidson Laboratory - Experimental Towing Tank damage. As a result, the wave heights of interest to this study have not been examined. The non-linear results as measured from smooth water to wave heights of 6 feet remove all possibilities for extrapolation of data to even 8 or 10 feet. Thus, any attempt to extrapolate data to wave heights of interest to this study must be accomplished on a purely qualitative basis.

As a result of this impasse, the takeoff and landing analyses cannot be performed to a degree which permit definite conclusions. Takeoff resistance analyses are computed for wave heights to 6 feet (available data) with an arbitrary extrapolation to 8 feet. Landing studies are included in this section wherein the initial impact loads are estimated based on representative wave profiles and certain approach and landing assumptions.

5.3 Analysis of Open-Ocean Takeoff Capability of CTOL- and STOL-Type Air-Sea Craft

The CTOL and STOL seaplanes are representative of the horizontal takeoff and landing type. The objective of this analysis to establish their takeoff resistance characteristics with increasing wave heights. This information provides a basis from which to specify the required thrust during takeoff with takeoff distance and associated time required as outputs. An attempt had been made to quantify the takeoff performance of a generic family of seaplanes in order to establish the degree of sensitivity to increasing wave height, or sea state, and to determine if there is a threshold in sea state beyond which the air-sea craft cannot operate. The limited engineering data has been confined to that obtained on dynamically similar models as tested by NASA up to 1959. Some seaplane work is currently being performed at Davidson Laboratory. These data are the only set which have been conducted under conditions permitting successful repetition because they were conducted in a tow tank.

During the study, Navy representatives and the CAL project group mutually generated a set of desirable requirements which influence the operational capabilities of a CTOL-type aircraft. The pertinent requirements are:

1. No hydroski(s) shall be used.

2. Take-off speed approximately 80 knots.

3. Hull length-to-beam ratio L/B of 15 to 20.

4. Hull dead rise angle approximately 40°.

These requirements evolved as a compromised solution to impact accelerations on landings, potential severity of wave encounters at high speed, and other updated design trends.

NASA has tested scale models in the Langley towing tanks. Some of the characteristics pertinent to those selected are presented in Table 2.

TABLE 2

NACA MODEL CHARACTERISTICS

Parameter	NACA TN 1570	NACA TN D-165
Full-size gross weight, W, lbs.	75,000	75,000
Takeoff speed, V_G, kns.	76	117
Wing Loading, W/S, psf	41.1	120
Length-to-beam ratio L/b	15[1]	15
Dead Rise angle β deg.	20	20[2]
Gross load coefficient $C_{\Delta o}$	5.88[1]	5.85[2]
Maximum beam, b ft.	5.84[1]	5.84

1. An L/b of 6 whose beam b = 10.76 ft. and $C_{\Delta o}$ = 10.76 was also tested.

2. Other dead rise angles of 40^{o} and 60^{o} and an additional $C_{\Delta o}$ of 6.45 were also analyzed.

Document TN-1570 (Reference 2) is confined to resistance measurements in smooth water while document TN D-165 (Reference 3) shows that the change in resistance coefficient C_R is negligible between dead rise values of 20° and 40° for a range of wave height-to-length ratios of 0 to .03. The value of 20° dead rise is a reasonable compromise for this takeoff resistance study; the effects of takeoff speeds, 76 and 117 knots, as reflected by wing loading, provides a much greater change of characteristics. It is recognized that while 20° and 40° dead rise showed little difference for the high takeoff speed seaplane, it may not follow that the same is true for the lower takeoff speed seaplane. In fact, Reference 4 shows that a 10% increase in resistance-to-load ratio results in a change of from 20° to 30° (max. value reported) in the planing region for smooth water. A logical recommendation is the initiation of rough-water tests for the selected configuration. However, the required data is lacking and the comparisons that follow are based on 20° dead rise to illustrate trends.

Figure 2 is a plot of integrated average resistance coefficients for various wave heights. They are plotted against Froude number. These curves apply specifically for an approximate 1/10th full-size powered dynamic model having various hull characteristics which are believed to be typical of good current practice. The humps occurring at the Froude number of 6 to 8 are a result of the hull reaching its planing velocity. The tests were limited to wave heights of approximately 6 feet full size because of restrictions imposed by the wave-making machine characteristics and model hazard. These curves have been used to suggest a method for evaluating the capabilities of representative designs for takeoff performance. Obviously their non-linearity and lack of uniformity obviates any attempt to extrapolate the data to higher wave heights.

In Reference 5, F. W. Locke has examined the general resistance relationships which may be used to satisfactorily collapse data for preliminary design purposes. His method separates the seaplane waterborne regime into two speed ranges, (1) the displacement range where buoyant forces predominate and (2) the planing range where dynamic forces predominate. In the

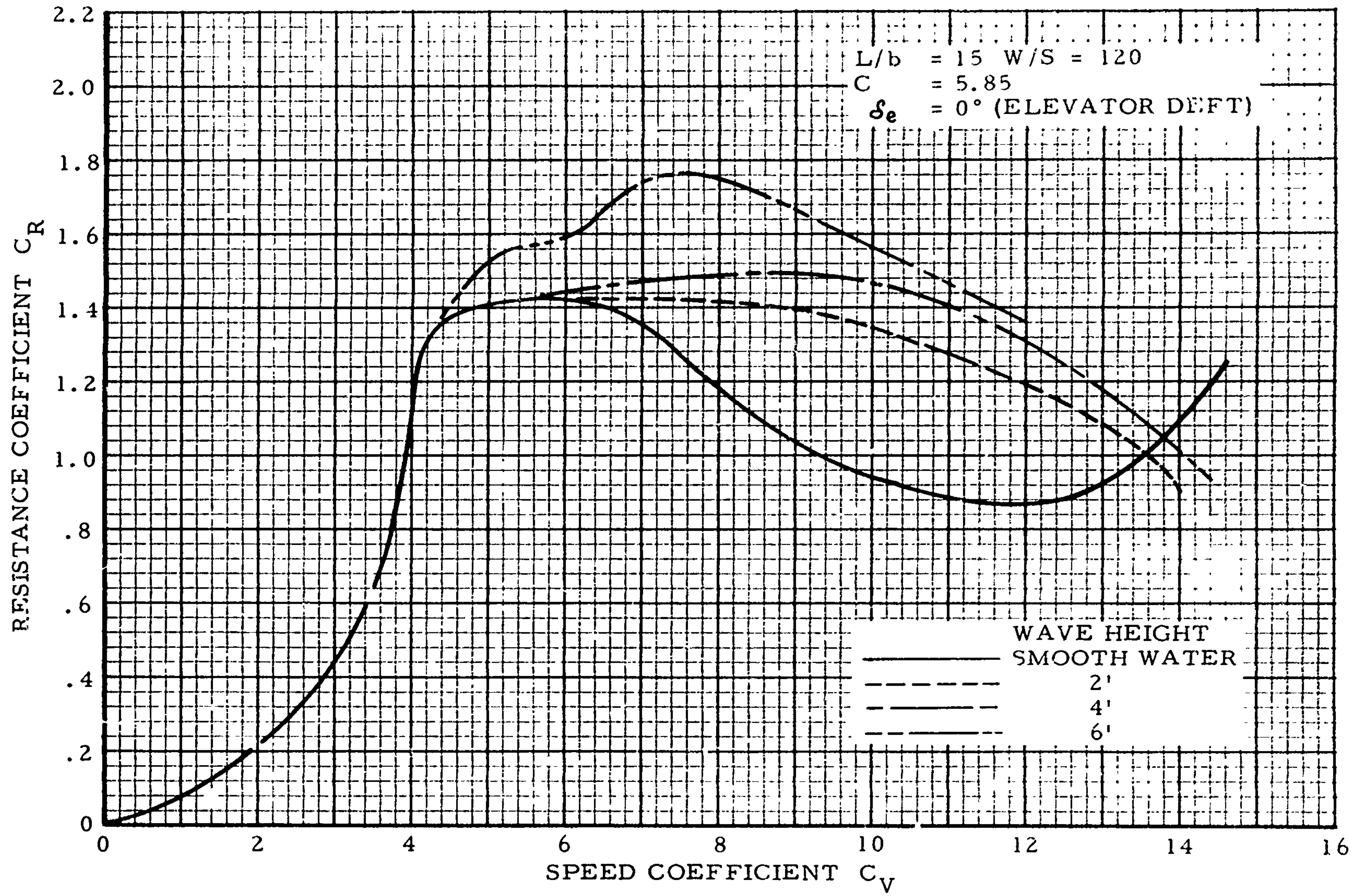

Figure 2 RESISTANCE COEFFICIENT VS SPEED COEFFICIENT FOR VARIOUS WAVE HEIGHTS

displacement region, resistances arise mainly from wave making. A resistance nondimensional parameter $(C_R / C^{2/3} C_V^2)$ and a speed parameter $(C_V^2 / C^{1/3})$ have collapsed the displacement range very well. Figure 3 presents the smooth-water lines for the 41-psf wing loading seaplane (the circles) and the 120-psf wing loading seaplane (the squares). The effects of high takeoff speed repositions the peak Y along the increasing speed parameter axis X. The peak Y value is diminished from .034 (V_G = 76) to .024 (V_G = 117). The solid symbols are values at the estimated hump speed. The intermediate solid lines which are fixed, are proportioned between the existing wing loading pair. If a linear relationship existed between peaks and hump speed points, then the solid curves would take on the intermediate wing loading values shown. Again, the lack of intermediate data does not permit a linear interpretation. It is suggested that dynamically similar model tests be conducted to fill in the gaps so that a better estimate of resistance parameters can be established.

Figure 4 is a resistance-speed parameter plot of the wave-height data given in Figure 2. It is interesting to note that seemingly uncorrelated data reorders so smoothly when plotted to these parameters. The value of C_Δ, the waterborne load coefficient, has been allowed to vary from the gross value at zero speed (C_{Δ_o} = 5.85) to C_Δ equal to 0 at takeoff according to a square law. The intermediate values of C_Δ are given by:

$$C_\Delta = C_{\Delta_o}\left[1-\left(\frac{C_V}{C_{VTO}}\right)^2\right]$$

Referring to Figure 4, the values for zero and two-foot waves follow the same curve and only their end points are different. The dashed line is arbitrarily added such that at each X a Δ Y from 4-foot to 6-foot waves is added to the 6-foot curve. If equal wave height effects on Y existed beyond 4-foot heights, this curve could be considered as 8-foot wave data.

In summarizing the attempt at generating generalized resistance data for the displacement speed range, it is suggested by the X - Y plots that prehump speed resistance data could be obtained from a limited number of

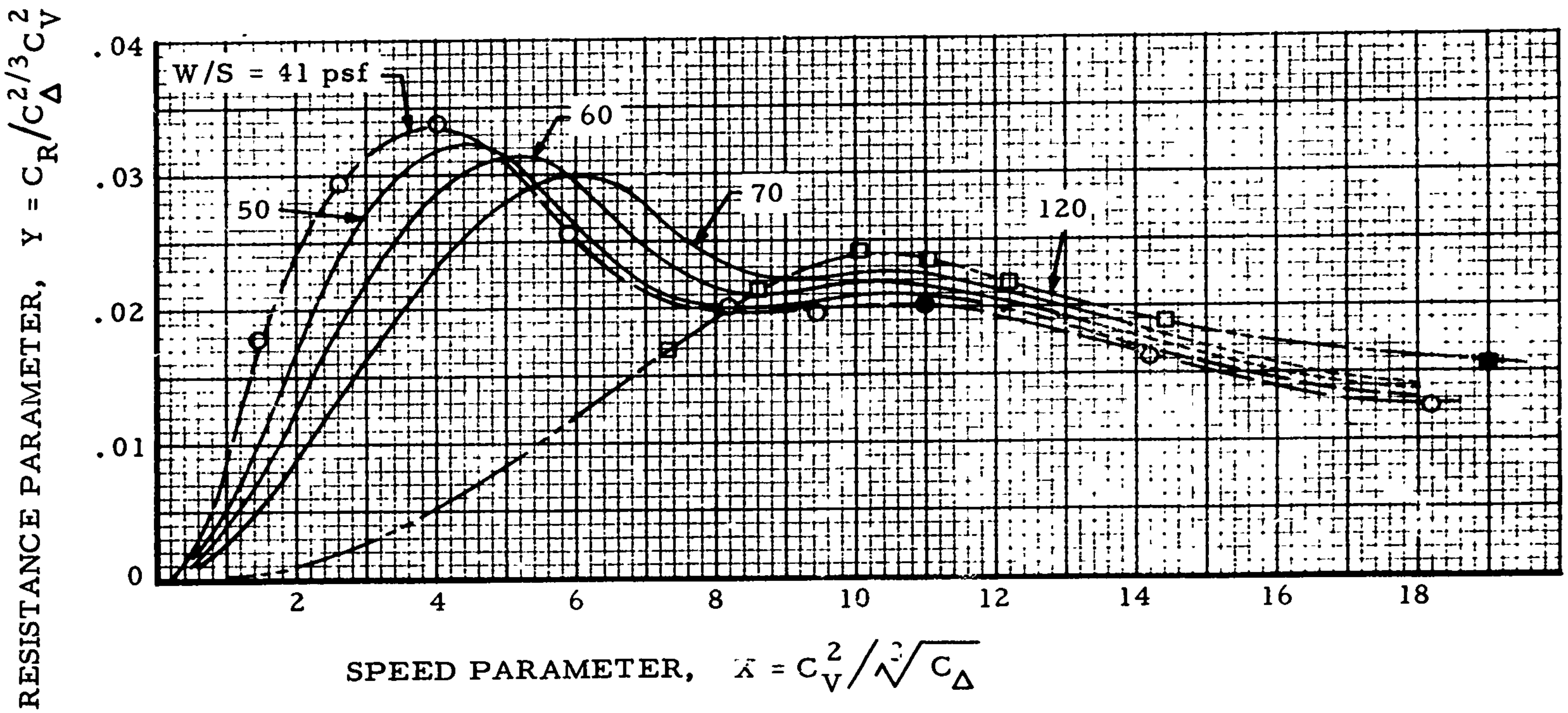

Figure 3 DISPLACEMENT RANGE RESISTANCE PARAMETERS AT VARIOUS WING LOADINGS - SMOOTH SEA

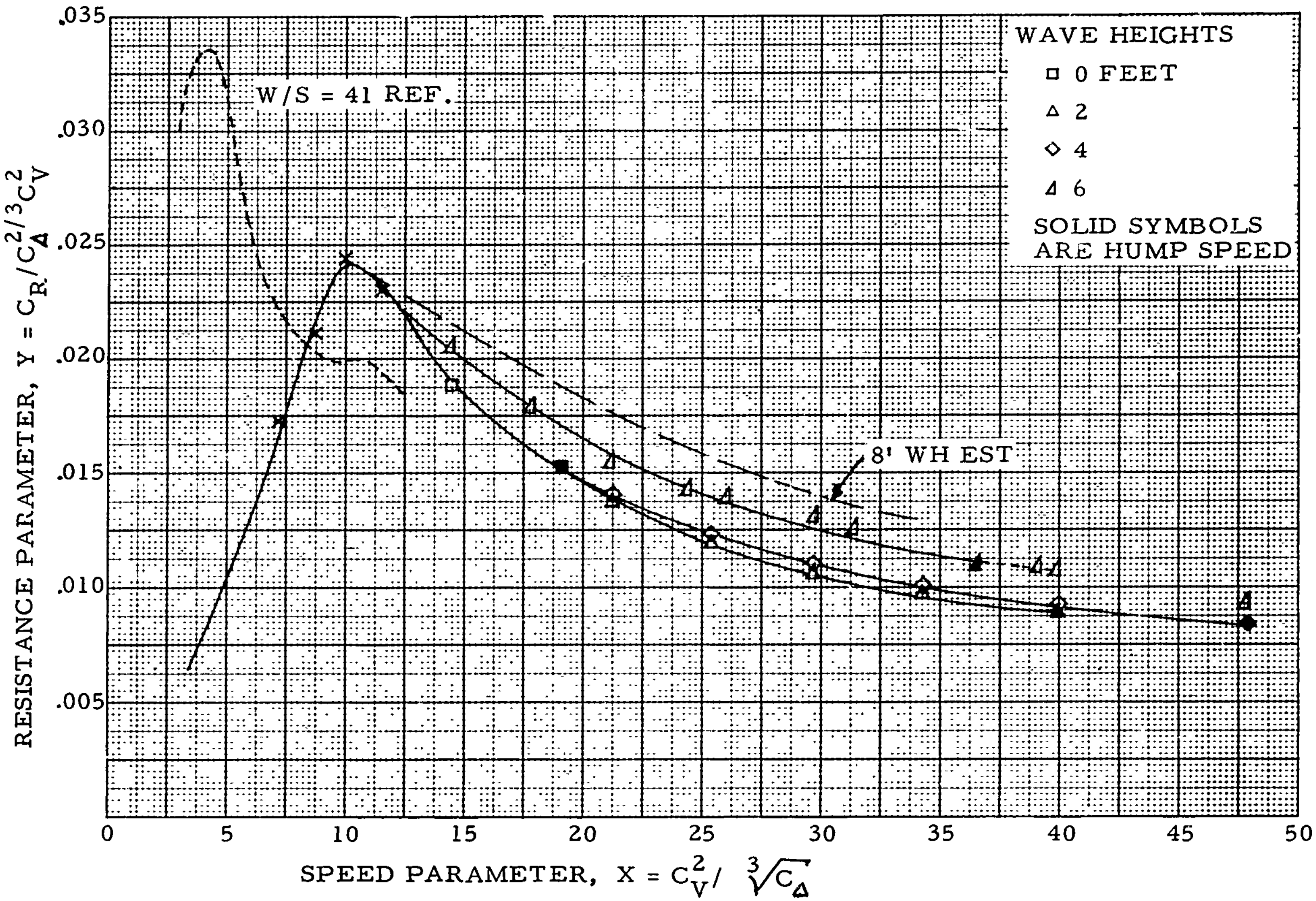

Figure 4 DISPLACEMENT RANGE RESISTANCE PARAMETERS FOR 120-PSF WING LOADING

test points if several wave heights were taken. Reference 5 has shown that the data collapses well even for relatively large changes of gross load coefficient. The impasse experienced in this effort has been the lack of wave-height data for the 41-psf wing loading case. Reference 6 contains two tests on a model of the P5M for wave heights to 6.6 feet full scale. The results indicate a large rate of change of resistance between waves 4.4 feet and 6.6 feet with little or no changes for the small waves. This follows the same trends shown in Figures 2 and 4.

The planing speed range has been examined by replotting the functions of a load-speed ratio parameter $\sqrt{C_\Delta} / C_V = X'$ and resistance-speed parameter $\sqrt{C_R}/C_V = Y'$. These parameters have evolved because the Froude number would become less important and resistance per unit of dynamic force would approach a constant. Figure 5 presents the planing region plots for the 41-psf loading (circles) and the 120-psf loading (squares). The latter curve is characterized by a discontinuity at X' of approximately .21 indicating a planing change from the afterbody to the forebody region, right to left respectively. Note that the zero is placed at the right side in keeping with past precedent and represents the takeoff point. Again, a linear proportion is arbitrarily taken for intermediate wing loadings. A check test at an intermediate loading would be necessary to establish the proper spacing. At takeoff, the spread is negligible and test points are a convenience, not a requirement.

Thus, a method of collapsing data in both displacement and planing regions have been presented. If the CTOL air-sea craft is a competitive candidate for open-ocean ASW operations, then model test data are needed to provide reliable resistance data. It is suggested that these tests be conducted in appropriate waves and the data plotted in a manner similar to that of Figure 6. This data presents the planing region results for the variable wave height data on the 120-psf seaplane wing loading. Here again, the seemingly unordered data of Figure 2 is reasonably uniform with the exception of the smooth-water curve (squares) which cross at the takeoff point. Dotted connections (X' = .142 and .21) are sketched in across the forebody/afterbody

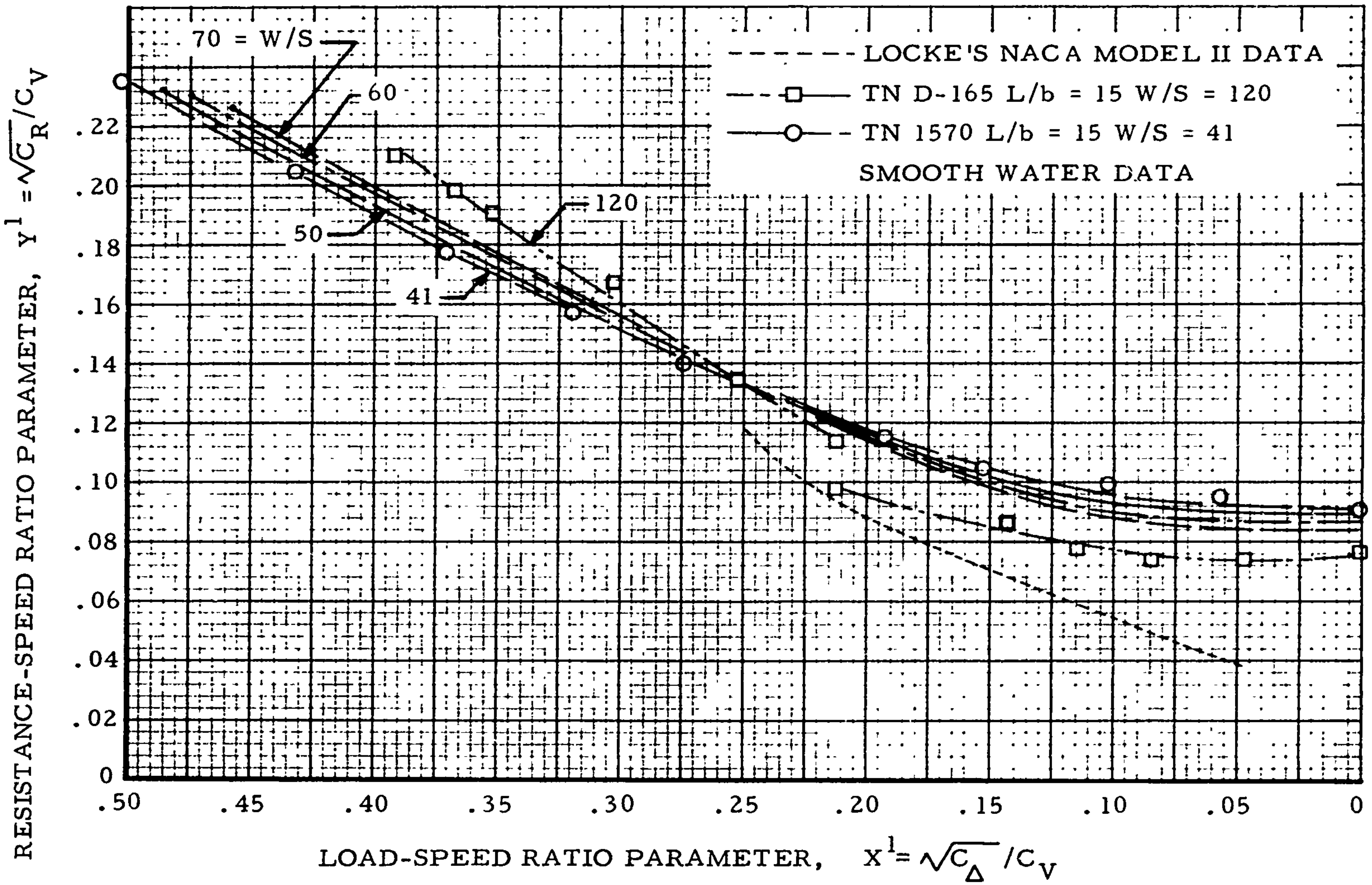

Figure 5 PLANING RANGE RESISTANCE PARAMETERS FOR VARIOUS WING LOADINGS – SMOOTH SEA

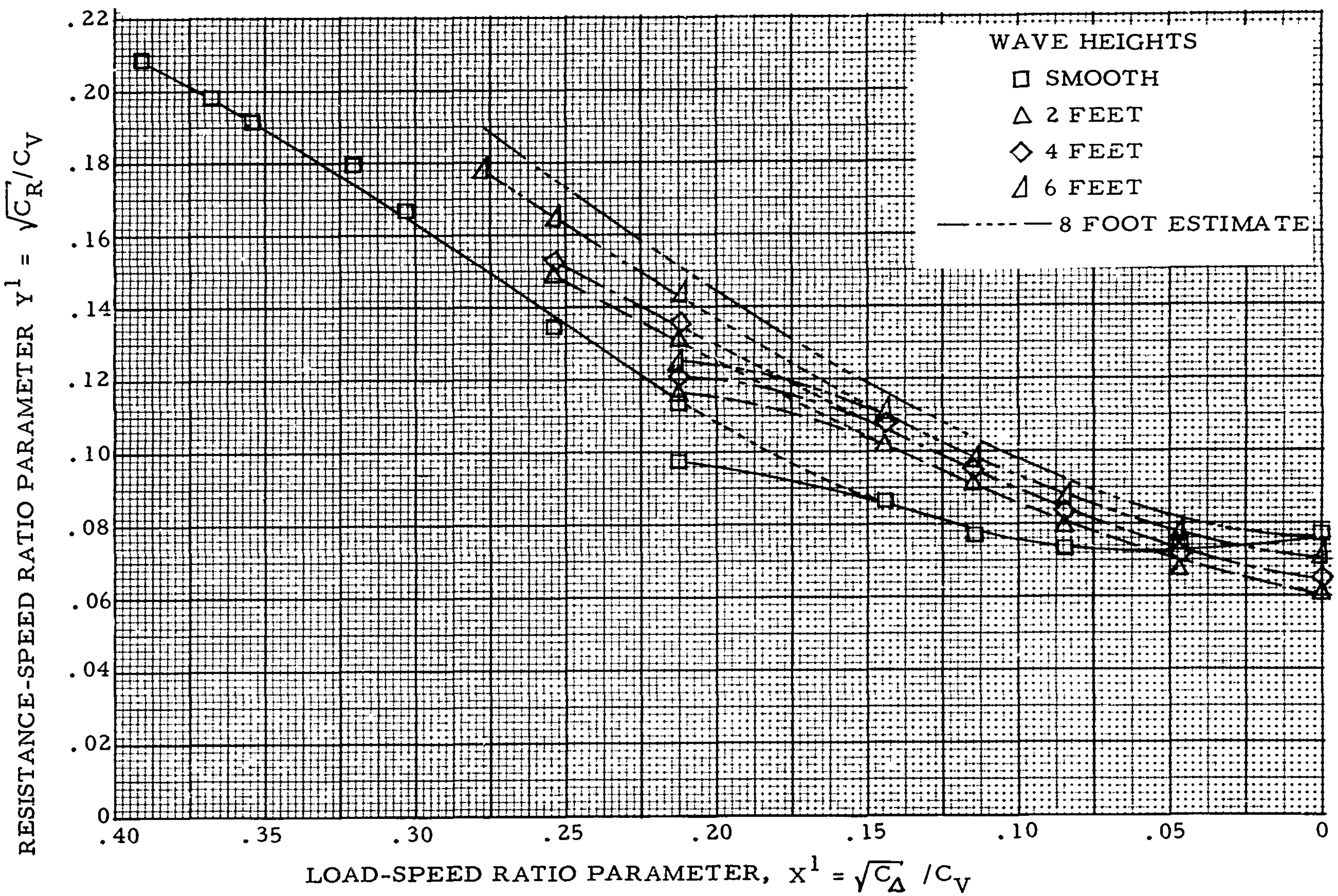

Figure 6 PLANING RANGE RESISTANCE AT VARIOUS WAVE HEIGHTS - WING LOADING = 120 PSF

discontinuity. If these data and those of Figure 4 had been obtained for the wing loading corresponding to the 80-knot takeoff speed selected, then a meaningful analysis could be performed on resistance encountered, thus permitting a determination of thrust required for reasonable takeoff distances.

5.4 Analysis of Pitch and Roll Control Requirements for VTOL-Type Air-Sea Craft with Sea Legs in Open-Ocean Takeoff and Landing Operations

Since any detailed work in this area is highly dependent on the particular configuration, a limited amount of effort has been made in one area. The VTOL-type air-sea craft have resorted to the use of sea legs as their means of buoyancy on the sea surface. As a result, the flight control requirements appear to be an important new consideration for the operation of these vehicles. The following work has examined, in a very general way, some implications arising from the use of long sea legs during the landing and takeoff flight modes.

A typical submitted design used in this analysis is shown in Figure 7. All dimensions have been normalized about the aircraft length in an attempt to provide generality to the conclusions to be drawn from this work. While many of the proportions shown may vary from design to design, the results of pitch and roll control requirements have indicated the importance of further study in this area. It is assumed that this air-sea craft is hovering just above the surface of the waves and headed into a 35-knot wind (59.1 ft. per sec.). Further, it is assumed that the diameters of the legs are all alike; a 3.5-foot diameter is chosen as a representative size and the drag or resistance of these floats has been computed for the 35-knot wind. Calculations show that considering a reasonable amount of surface roughness, the flow about the sea legs is below the critical Reynolds number. A typical drag coefficient of C_D is equal to 1.2. The total area of all sea legs exposed to the wind is equal to $.059L^2$ and the net drag is equal to $.295L^2$ pounds.

The results of the calculations show that the moment about the center of gravity is equal to $.070L^3$ ft. lbs.

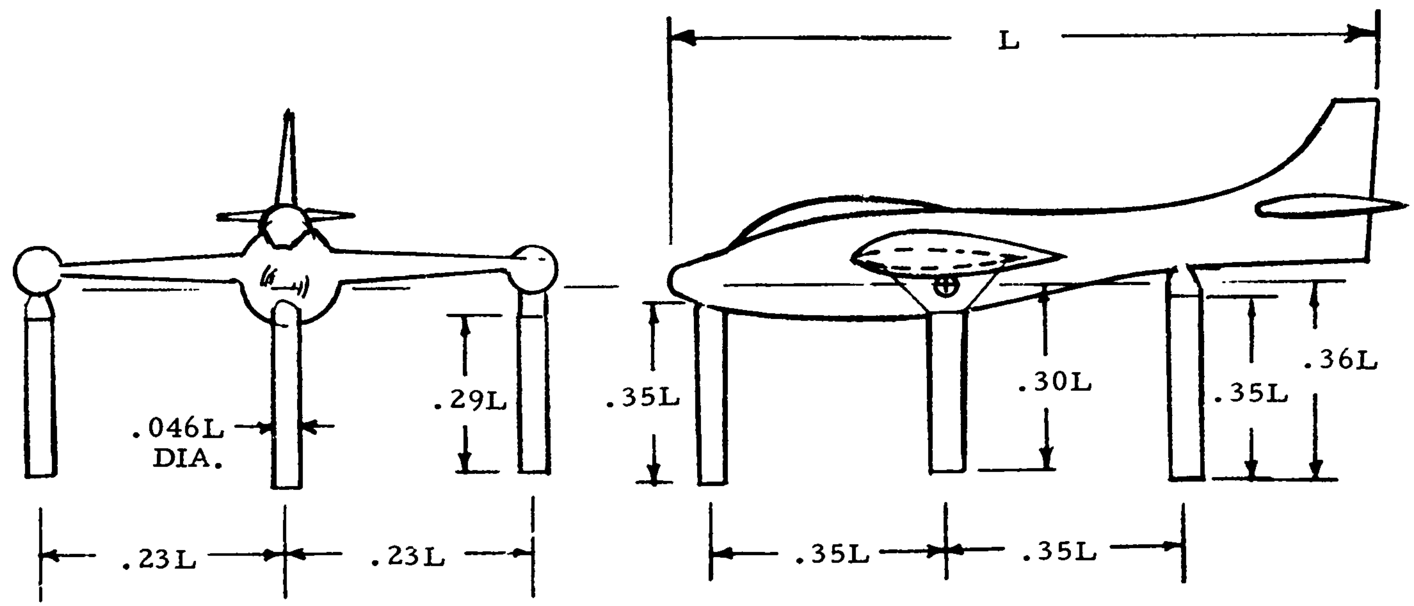

Figure 7 HYPOTHETICAL AIR-SEA CRAFT WITH SEA LEGS (NORMALIZED ABOUT LENGTH)

It has also been assumed that the air-sea craft has been headed into the wind. If it were oriented 90° to the wind, then this same magnitude of moment would produce a roll of the air-sea craft.

Figures 8 and 9 are the result of a 1960 study at Cornell Aeronautical Laboratory (Reference 7) wherein the design features of typical VTOL aircraft were examined. Figure 8 presents the angular acceleration required for roll control of a large number of VTOL or hovering type of aircraft. Remembering that these aircraft are not equipped with sea legs, these values are assumed to represent design trends for land-based vehicles of these types.

Figure 9 presents the same type of data for pitch. The value assumed for roll for a conventional type VTOL is 1.4 radians/sec.^{2} and for pitch, 0.8 radians/sec.^{2}. These are the suggested design values in the Cornell study. Note that both pitch and roll indicate a general tendency toward reduced design values of angular acceleration with increasing gross weight. This study assumes a single set of values for any gross weight as a first cut to examine the incremental control moment required to overcome the 35-knot wind on the extended sea legs. The analysis has been normalized about the length by taking typical ratios of length for the radii of gyration and a typical value of weight per unit length (W/L = 17) is assumed for the family of hovering craft considered at this time. As a result, the non-sea leg equipped air-sea craft would normally be provided with the following control capabilities:
normally be provided with the following control capabilities:

For roll	$.0857L^3$	ft. lbs.
For pitch	$1.660L^3$	ft. lbs.

Had the hovering type air-sea craft been designed for non-sea leg operation, the above static moments are representative of design values. The moment of $.070L^3$ ft. lbs. is an added requirement for the sea legs in a 35-knot wind. The increase in design requirements is therefore a factor N given by:

Roll	N = 1.82
Pitch	N = 1.04

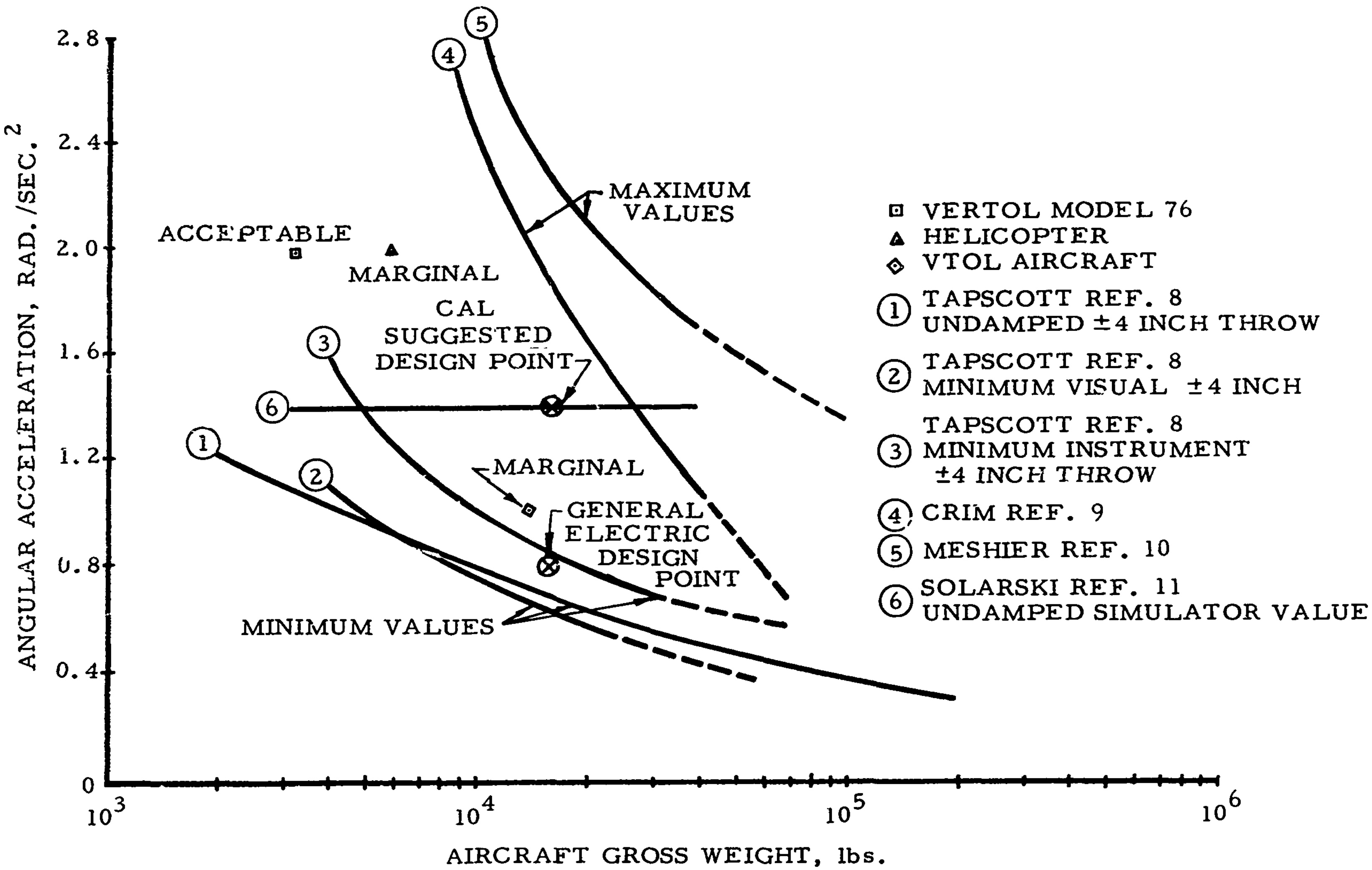

Figure 8 CRITERION FOR DETERMINING ROLL CONTROL REQUIREMENTS FOR VTOL AIRCRAFT (OUT OF GROUND EFFECT)

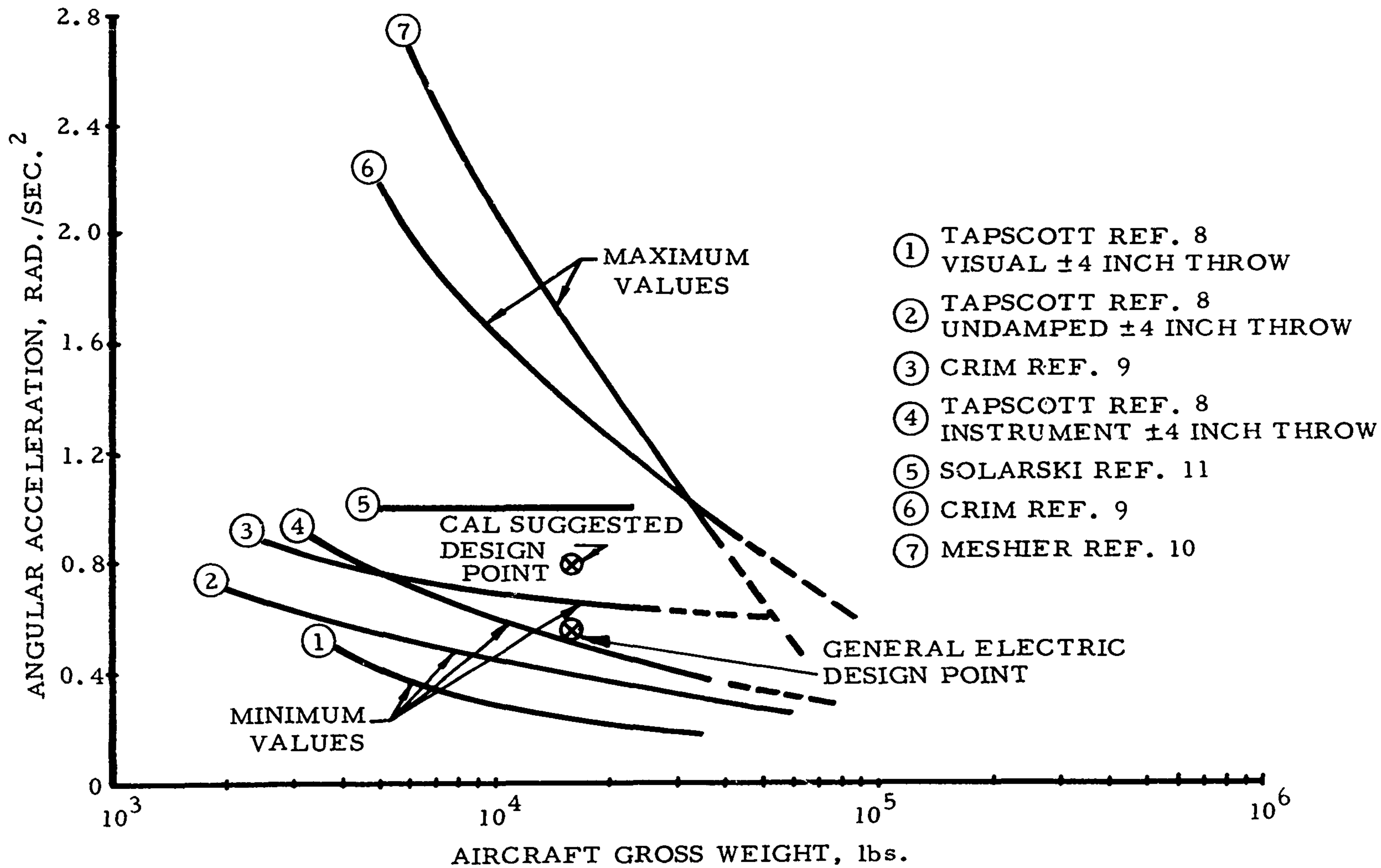

Figure 9 CRITERION FOR DETERMINING PITCH CONTROL REQUIREMENTS FOR VTOL AIRCRAFT (OUT OF GROUND EFFECT)

Therefore an 82% increase is needed in roll, but a negligible 4% increase in pitch control is needed. This suggests that given these added control capabilities, the handling characteristics in roll will differ widely with and without sea legs unless a gain change in linkage or some such feature is added.

Since the lateral drag due to wind just prior to landing (or at takeoff) is significant in roll, it is reasonable to assume that an asymmetrical dunking of the sea legs may generate severe upsetting moments. Consider the air-sea craft in a situation as shown in Figure 10 wherein it is drifting laterally and dips a sea leg into a wave peak. The spray/wave resistance R may be estimated from partial submergence data on struts. Reference 12 presents compiled data of C_D for cylinders partially submerged in water. Assuming a relative velocity of the water at the sea leg of 10 knots, hence a Froude number of about 1.6, the value of $C_D = 0.9$. The resultant resistance expressed as a function of length is $.19L^2$ lbs; the moment is $.053L^3$ ft. lbs., a value of about 75% of the air moment at 35 knots. The moment caused by the air may very well be applied simultaneously with the dunk-moment. If this occurs, the 1.82 factor would become 2.44; the required control due to an asymmetrical dunk alone yields a factor of 1.62.

If these high requirements are compromised, then pilot training is necessary to minimize or remove the occurrence of the situation if possible. This is an impractical solution of itself; more work is needed in this area since so many other potential gains appear attractive from the use of sea legs.

5.5 Analysis of Open-Ocean Landing Capability of CTOL- and STOL-Type Air-Sea Craft

A brief examination has been conducted of the landing air-speeds and impact accelerations expected for CTOL- and STOL-type air-sea craft.

5.5.1 Landing Impact Load Factors Analysis

A preliminary analysis of the air-sea craft load factors incurred during the initial landing impact has been conducted using the methods presented in References 13, 14 and 15. The effect of wind on the landing

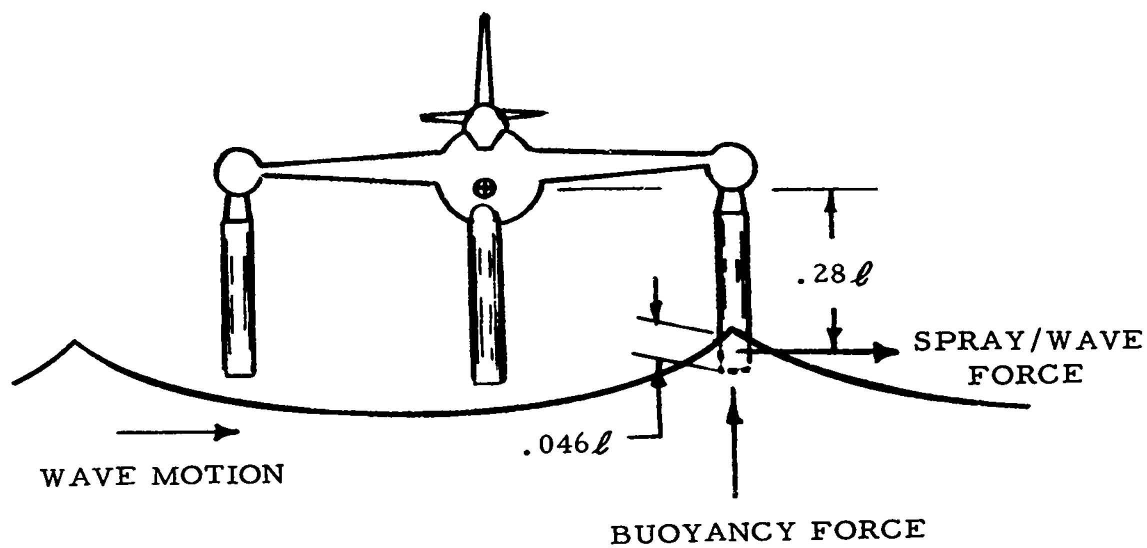

Figure 10 VTOL AIR-SEA CRAFT TYPICAL LANDING OR TAKEOFF SITUATION (WITH DEPLOYED SEA LEGS)

ground speed of the air-sea craft has been estimated using the minimum wind speed expected. Figure 11 shows the minimum and average wind speeds as a function of wave height. The minimum wind speed data has been taken at the 10% probability of occurrence level (e.g. 90% of the time the wind speed is greater). These data have been determined from an annual average of wave height vs. wind force in the worst weather sector of the Argentia-Azores ASW barrier (presented in Volume III of this report).

The basic assumptions for the analysis were:

1. Rate of descent of the air-sea craft equals a constant 200 feet per minute
2. Deadrise angle of hull = 40°
3. Effective trim angle = 5° (10° for low wave slopes)
4. Equivalent horizontal propagation speed of the wave equals a constant 30 fps for all wave heights.
5. Landing into the minimum headwind expected for each wave height
6. Landings into the maximum wave slope
7. Only initial impact normal acceleration (load factors) are determined (the effects of subsequent bounces are not considered)
8. Landing impact is at the step location
9. Weight range = 25,000 to 300,000 lbs.

Calculations were performed for maximum wave slopes of 5°, 10°, and 15° and these wave slopes correlated with wave height. The assumed wave slope as a function of wave height was derived from statistical data for the North Atlantic. A linear variation was assumed between 5° maximum wave slope for 2-foot wave height and 15° slope for 30-foot waves. Approximately 75% of the waves will have less maximum slope than the assumed variation. Figure 12 presents a sample plot of the impact load factors for a wave slope of 10° as a function of landing weight and landing speed without wind effect

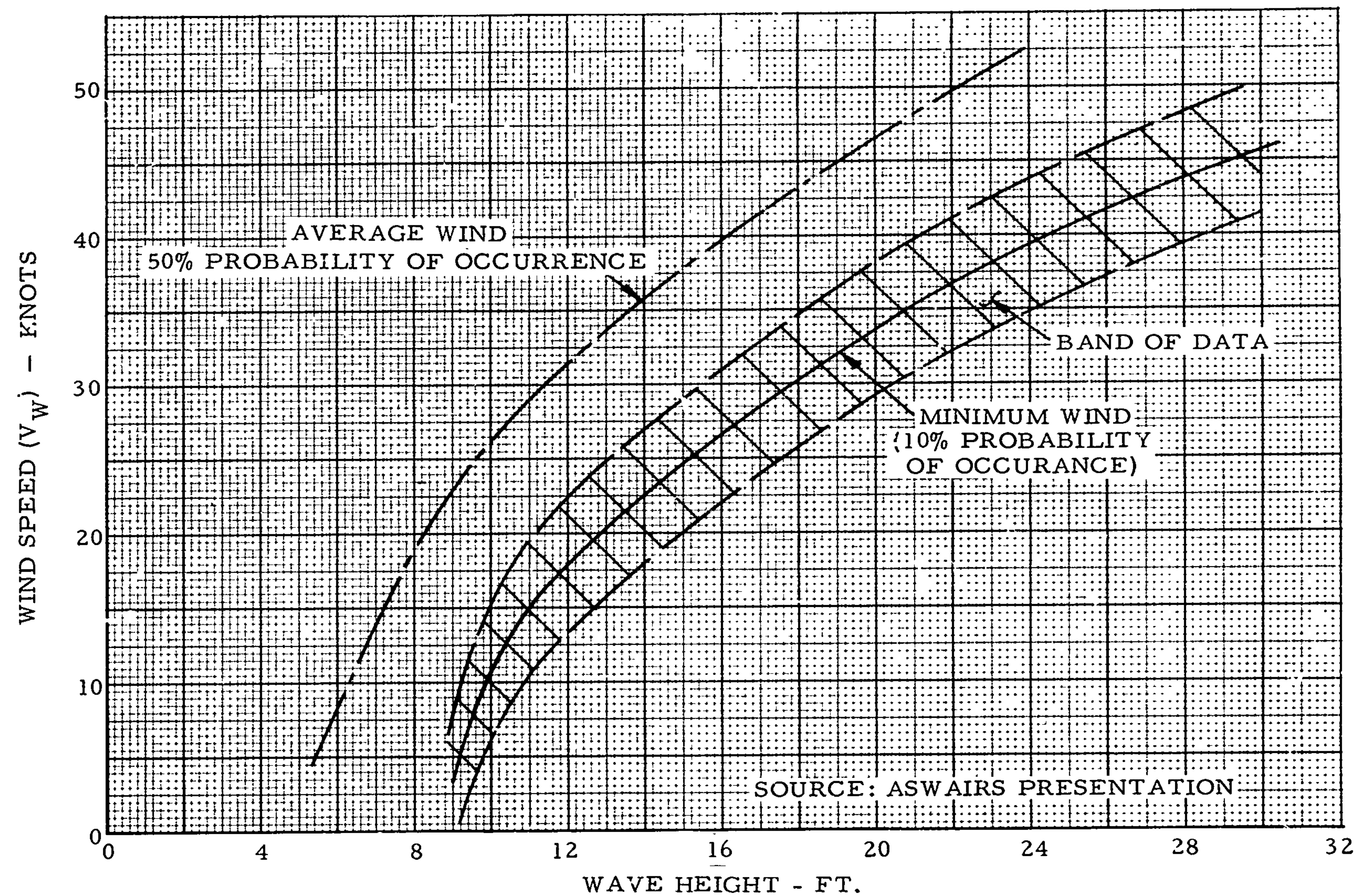

Figure 11 AVERAGE AND MINIMUM WIND SPEED VS WAVE HEIGHT (WHERE $V_W >$ THAN INDICATED $V_{W_{MIN}}$ 90% OF THE TIME)

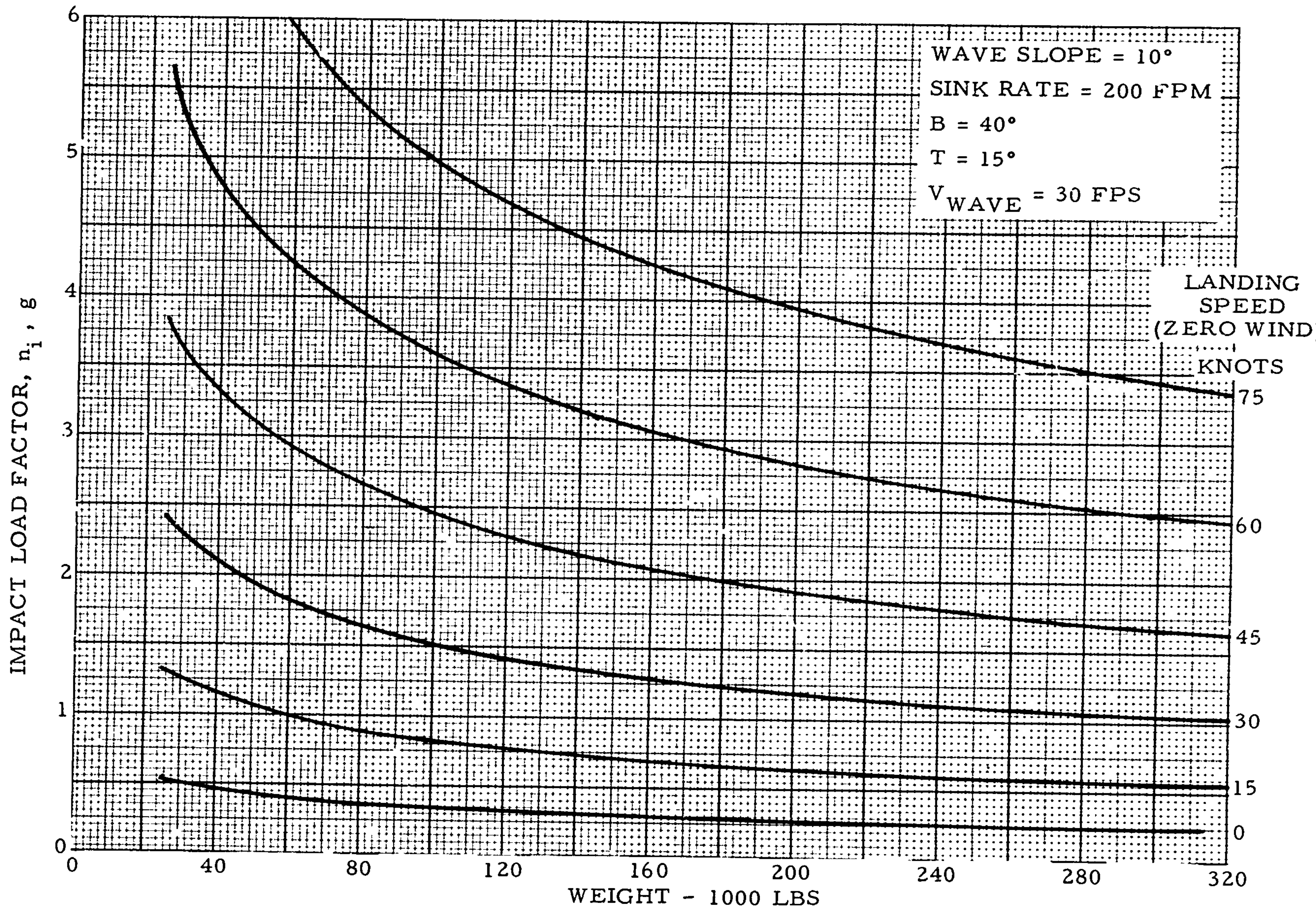

Figure 12 LOAD FACTOR VS. WEIGHT AS A FUNCTION OF LANDING SPEED

included. Figure 13 replots the data of Figure 12 for constant values of impact load factor to indicate the maximum zero-wind landing speed as a function of weight.

The minimum wind speed as a function of wave height has been correlated between Figure 11 and the assumed wave slope vs. wave height variation. Landing impact accelerations (load factors) have then been determined accounting for the minimum expected headwind. Figure 14 presents a plot of impact load factor for a 75,000 lb. air-sea craft as a function of wave height and landing true airspeed (TAS) with the wind effect included. For an air-sea craft with a 75-knot landing airspeed, the impact load factor is shown to remain constant with increasing wave height, indicating that the wind effect is compensating for the increased wave slope. For the 60-knot air-sea craft, and particularly for the 45-knot air-sea craft, representative of STOL types, a reduction in the initial impact load factor occurs as the sea state increases because of the wind effect.

Figure 15 presents a plot of the impact load factor as a function of wave height to indicate the significant effect of the wind. For zero wind, the load factor increases rapidly with wave height. Assuming landing against the minimum headwind (10% of the time), the load factor remains approximately constant with wave height. With the average wind, the load factor reduces with wave height. It is to be noted that the calculations are for the initial landing impact and if the seaplane is subject to bounces during the landing run due to wave encounters, more severe load factors may well be developed.

The results of the landing impact analysis are presented on Figure 16. The maximum landing airspeed is plotted as a function of wave height for maximum impact load factors of 3.0, 4.0, and 5.0 g. The landing true airspeed (V_L) is a function of the configuration and propulsion of the seaplane and the impact load factor is a function of the structural design. For air-sea craft designed to withstand only 3.0 g impact load acceleration, the landing airspeed must be kept significantly lower than if 4.0 or 5.0 g could be accepted. A 75,000-lb. air-sea craft landing in 20-foot waves could accept the following maximum airspeeds:

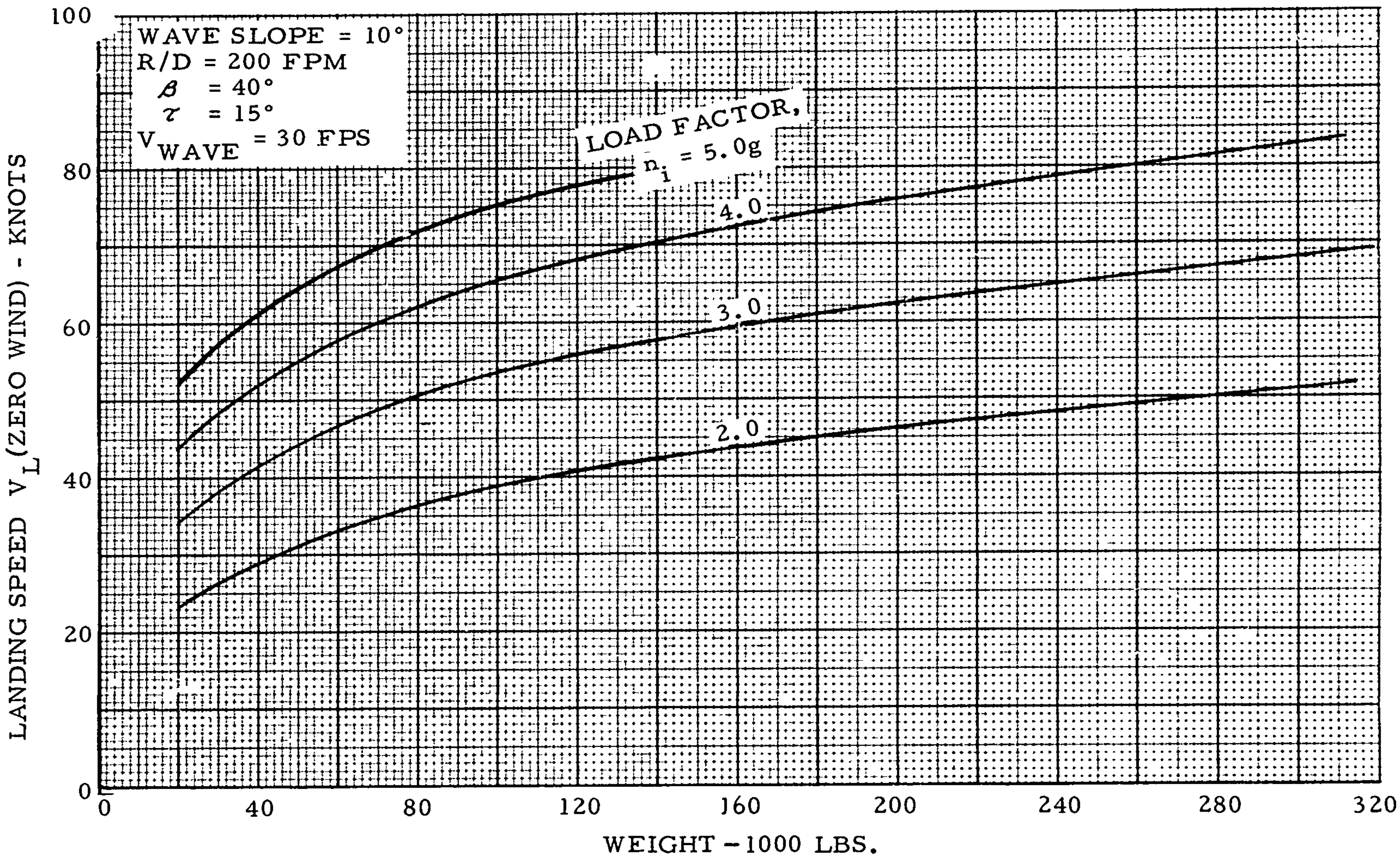

Figure 13 LANDING SPEED IN ZERO WIND VS WEIGHT AS A FUNCTION OF LOAD FACTOR

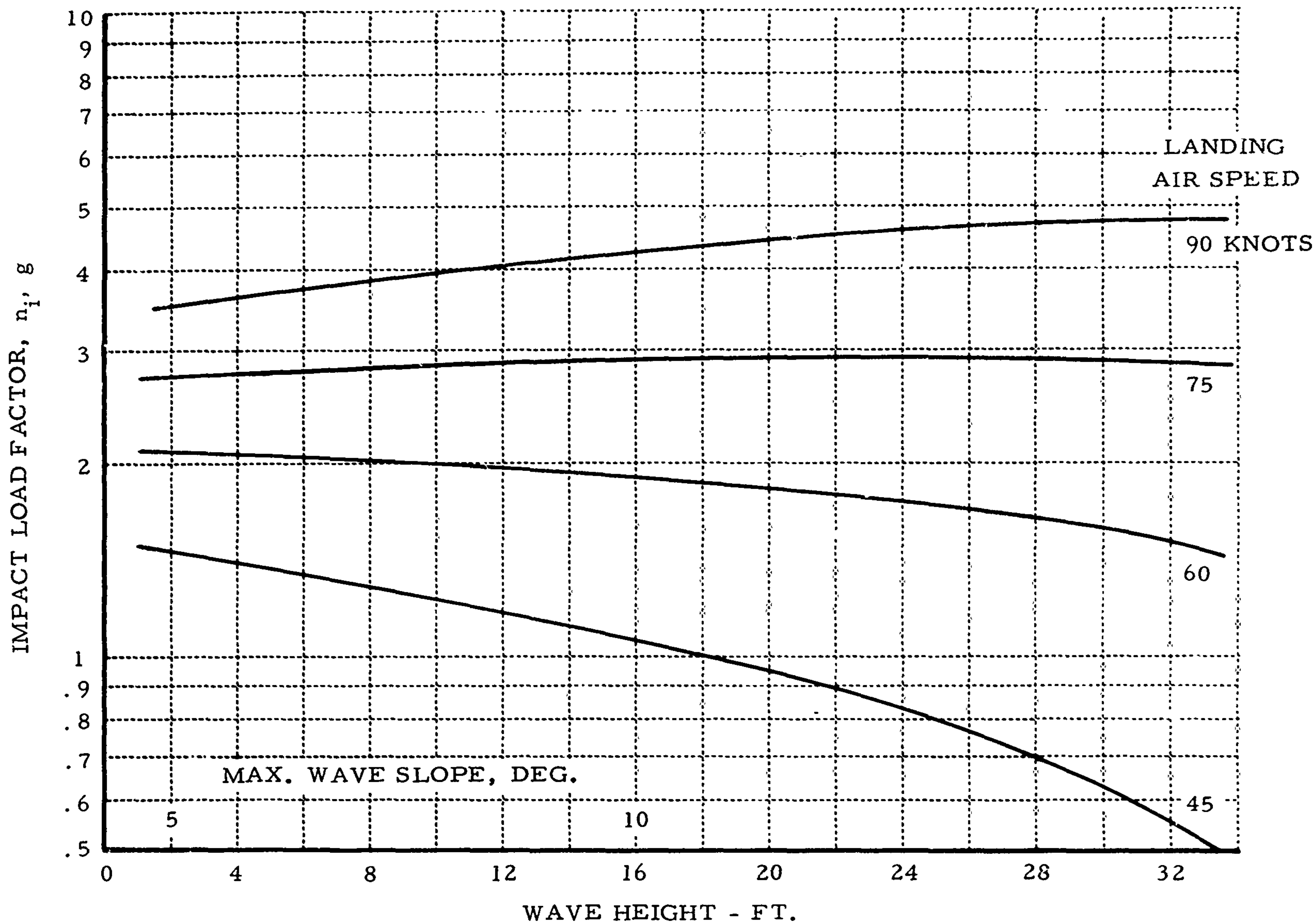

Figure 14 LOAD FACTOR VS. WAVE HEIGHT AS A FUNCTION OF LANDING SPEED FOR W = 75,000 LBS

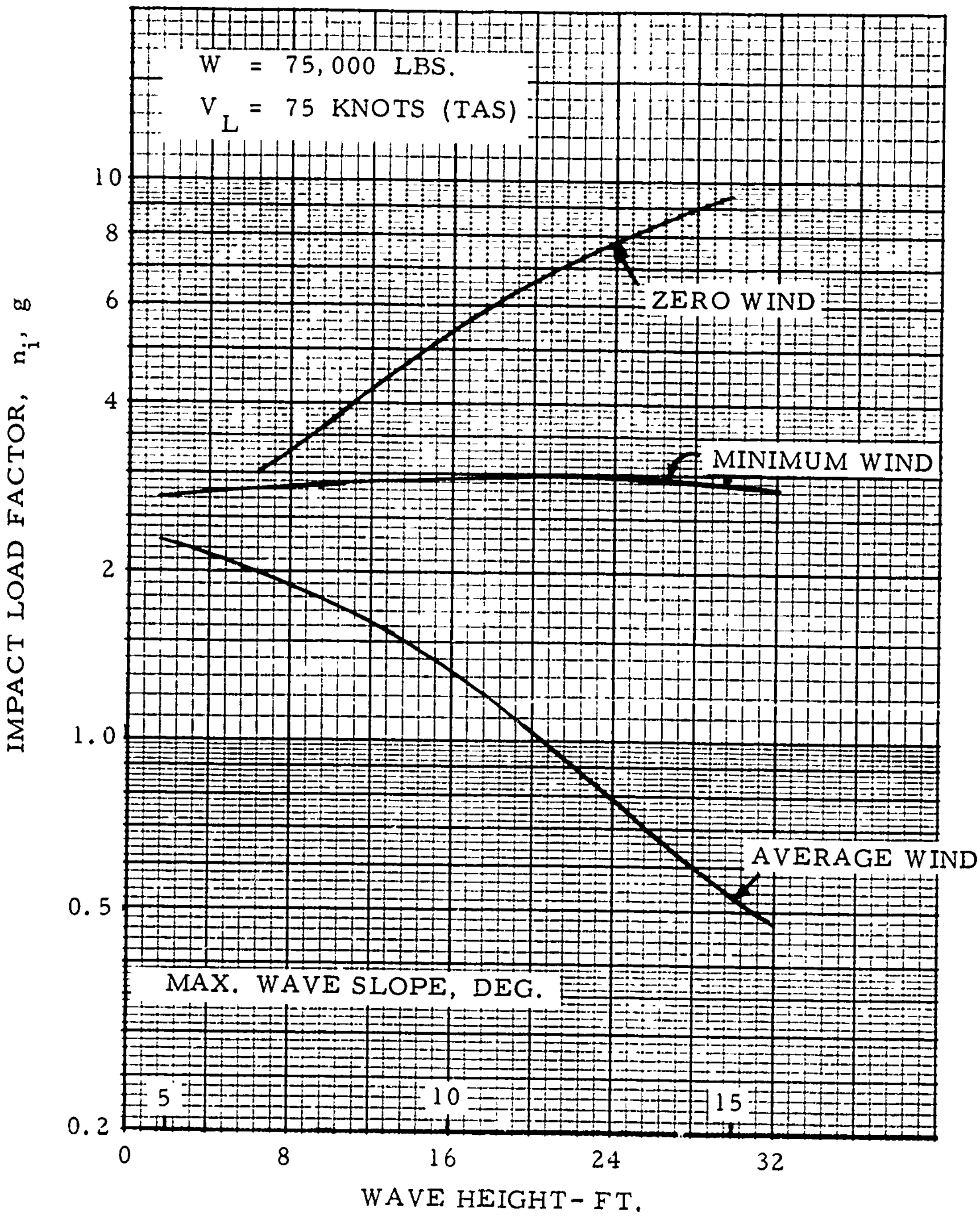

Figure 15 EFFECT OF WIND ON LANDING IMPACT LOAD FACTOR

LANDING INTO MINIMUM WIND AND INTO MAXIMUM WAVE SLOPE: R/D = 200 FPM, β = 40°, V_{WAVE} = 30 FPS

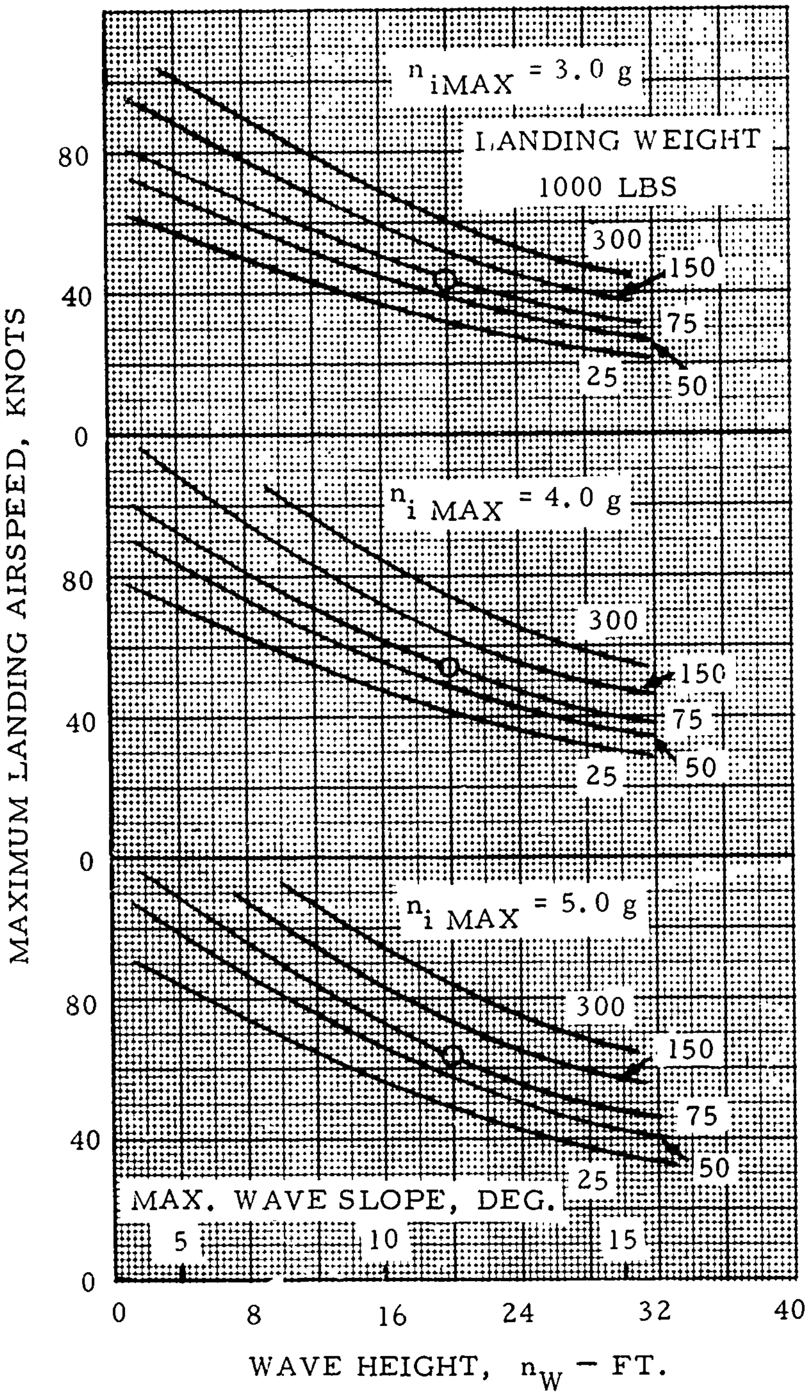

Figure 16 MAXIMUM LANDING AIRSPEED vs WAVE HEIGHT

Design Impact Load Factor, g	Max. Landing Airspeed, (20-ft. waves), knots
3.0	44
4.0	53
5.0	62

5.5.2 Summary of Results

The following table presents a summary of the analytical study of impact load factors and wave heights.

TABLE 3

SUMMARY OF LANDING AIRSPEED - WAVE HEIGHT TRADEOFFS

Design max, impact load factor ($n_{i_{max.}}$) = 4.0 g

Landing weight, lbs.	Maximum Wave Height, ft. True Airspeed, V_L - Knots		
	45	60	75
25,000	18	9	2
50,000	22	14	10
75,000	26	17	12
150,000	>30	22	15
300,000	>30	27	20

It is emphasized that these values have been determined using methods developed from experimental studies and statistical data. Direct application to operational air-sea craft must include consideration of many other factors, such as actual sea and wind variations, subsequent bounces following initial impact, and low-speed control about the three rotational axes (pitch, roll, yaw). The method employed to calculate the initial landing impact assumes landing on the step and does not consider the effect of hull configuration aft of the step, (e.g. the length-to-beam ratio of the hull is not a parameter in the analysis).

In summary, it is evident that much of the information available to this study is based on assessments which border on subjective evaluation. This fact is due principally to the dynamic nature of the various air-sea craft, which causes the behavior of the vehicle to be dictated by detailed mass distribution, geometric size and shape, configuration type, and many idiosyncracies, rather than by any particular single phenomenon which would be unique to each air-sea craft configuration.

The employment of STOL-type air-sea craft in open-ocean ASW operations will substantially increase and improve sea state operating capability and safety in comparison with conventional seaplanes, such as the P5M or P6M type, due to lower flying speeds during lift-off and touchdown operations (i.e., $<$ 50 knots). The addition of a hydroski will reduce wave impact loads on the hull of those air-sea craft requiring higher speeds during takeoff and landing. The size of the air-sea craft will also be an important consideration in determining sea state operating capability, because for large vehicles, the ratios of wave length, height, and period to hull size are reduced. The addition of boundary layer control (BLC), slipstream control, or auxiliary reaction controls to provide positive control at low flight speeds will be mandatory.

Open-ocean operating capability, in addition to takeoff and landing considerations, is also dependent on sea-sitting capability. The employment of a sea leg floatation system will reduce the motions of air-sea craft while sitting on rough seas. It is expected that the sea-sitting mode will not be the limiatation on the operational capability of CTOL- or STOL-type air-sea craft since takeoff and landing operations in high sea states will establish the operational limit.

Further analysis in various areas is necessary to establish more objective assessments of some of these designs. It would be advisable to re-examine the concepts and, if possible, eliminate some by collective engineering judgment so that in the interests of economy the remaining and more attractive configurations could be examined in considerably more detail. It is believed that only in this way will the feasibility of air-sea craft to ASW missions be established when considering the constraints imposed by the varying roughnesses of the sea.

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1.0 INTRODUCTION

1.1 Air-Sea Craft Vehicles and Acoustic Sensors

The purpose of this part of the study is to derive a set of selected candidate air-sea craft systems which are capable of performing the ASW missions under study. These missions are: barrier operations, task group and convoy screening, contact area investigation, and localization and attack. The approach to the problem is to first assemble a set of potential candidate systems from all possible combinations of mission profile vehicles (Tables 4 through 9) and sonar systems (Table 14). These potential systems are tabulated in Tables 16 through 19. The next step is to perform the operations analysis of the ASW missions in order to determine the requirements placed on air-sea craft in these missions. Finally, the air-sea craft requirements are matched as closely as possible with the capabilities of the potential candidate systems to derive the desired set of selected candidate systems. The selected candidate systems, with their associated sonar systems and the missions they are capable of performing, are presented in Table 20.

1.2 Mission Profiles

The air-sea craft have been sized to meet the requirements of four mission profiles (sets of performance specifications), selected by ONR to span the probable range of interest. Table 4 presents a summary of air-sea craft mission profile capabilities as specified by ONR in their request to contractors to submit potential air-sea craft designs. The ASWAIRS Project Group added Mission Profile 1A having an 8000-pound payload requirement because the 5000-pound payload assigned to mission profile 1 was found to be marginal for useful ASW operations.

TABLE 4

SUMMARY OF ONR AIR-SEA CRAFT MISSION PROFILES

Air-Sea Craft Parameter	ONR MISSION PROFILE				
	1	1A[1]	2	3	4
Radius, n. mi.	500	500	1000	1000	1000
Cruise Speed (desired/minimum), knots	300/200	450/200	350/300	300/200	300/200
Air Search Endurance at 1500 ft., hrs.	1	1	3	4	4
Waterborne Endurance, hrs.	6	6	6	20	50
Number of Water Takeoffs and Landings in Operating Area	3	3	8	12	16
Crew	4	4	12	14	21
Mission Duration, hrs.	10	10	15[2]	30[3]	60[4]

1. CAL-Formulated for 8000 lb. payload capability
2. Maximum for single crew
3. Minimum Relief Crew
4. Double Crew

2.0 AIR-SEA CRAFT CANDIDATE SYSTEMS

2.1 Air-Sea Craft System Components

The candidate air-sea craft systems are composed of combinations of:

1. Air-sea craft vehicles
2. Nonsensor systems (avionics, weapons)
3. Sensor systems.

These components are described by means of a series of tables which summarize the characteristics and performance capabilities relevant to the operations analyses.

2.1.1 Vehicles

The principal characteristics and performance of all generic types of air-sea craft analyzed in Volume IV are presented in Tables 5 through 9 for Mission Profiles 1, 1A, 2, 3 and 4 respectively. The air-sea craft vehicle types* examined are:

a. Mission profile 1

Basic CTOL-TP**

CTOL/STOL-TP with and without sea legs***

CTOL/STOL - RTP and CF with and without sea legs***

VTOL-TP with sea legs

STOPPED ROTOR VTOL-RTP with sea legs

GETOL-RTP with sea legs

---

* Refer to Subsection 2.1.1, item (d) for nomenclature list.

** Basic CTOL-types for all mission profiles are without sea legs, boundary layer control or hydroski.

*** CTOL/STOL-types for all mission profiles have CTOL with hydroski and STOL with boundary layer control.

b. Mission profile 1A

Basic CTOL-TP

CTOL/STOL-TP with and without sea legs

CTOL/STOL-RTP and CF with and without sea legs

VTOL-TP with sea legs

STOPPED ROTOR VTOL-RTP with sea legs

GETOL-RTP with sea legs

c. Mission profiles 2, 3, 4

Basic CTOL-TP

CTOL/STOL-TP with and without sea legs

CTOL/STOL-RTP and CF with and without sea legs

STOPPED ROTOR VTOL-RTP with sea legs

GETOL-RTP with sea legs

d. The following list defines the nomenclature used to designate various types of air-sea craft under items a., b., and c. above:

CTOL	Conventional takeoff and landing
STOL	Short takeoff and landing
VTOL	Vertical takeoff and landing
GETOL	Ground effect takeoff and landing
TP	Conventional cycle turboprop and turboshaft engines
RTP	Regenerative cycle turboprop and turboshaft engines
TF	Turbofan
CF	Cruise fan (high bypass ratio turbofan)
SR	Stopped rotor

TABLE 5

CANDIDATE AIR-SEA CRAFT VEHICLE DESIGN CHARACTERIS

FOR

ONR MISSION PROFILE 1

Air-Sea Craft Vehicle Characteristic	AIR-SEA CRAFT VEHICL				
	Basic CTOL-TP	CTOL/STOL-TP With Sea Legs	CTOL/STOL-TP Without Sea Legs	CTOL/S With Sea Legs RTP	
Mission Radius - n. mi.	500 ←				
Cruise Velocity - Kn.	200-250 ←		→	200-250	40
Takeoff Gross Weight - lbs.	30,000	43,000	33,700	34,000	34
Payload - lbs.	5,000 ←				
Useful Load - lbs.	11,720	14,400	12,500	10,700	10
Fuel - lbs.	5,920	8,600	6,700	4,900	4
Crew Number and Weight - lbs.	4-800 ←				
Airframe Weight - lbs.	10,050	17,160	11,660	14,120	16
Propulsion Weight-lbs.	3,660	5,150	4,240	5,360	3
Equipment Weight - lbs.	4,570	6,290	5,300	3,730	3
Cruise Efficiency - n. mi. /lb. ave	.259	.181	.231	.317	
On Station Airborne Endurance - hrs.	1 ←				
On Station Waterborne Endurance - hrs.	6 ←				
Total Mission Duration - hrs.	10 ←				

* Depending on type of Air-sea craft vehicle design.

** This vehicle is below the weight range where useful load-to-takeoff gross weight ratio and nautical mile per lb. of fuel data are available. Therefore caution should be used if this design is considered as a candidate for cost-effectiveness evaluation.

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N CHARACTERISTICS AND PERFORMANCE SUMMARY

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DN PROFILE 1

CRAFT VEHICLE TYPES						
CTOL/STOL-RTP and CF				VTOL-TP With Sea Legs	SR/VTOL-RTP With Sea Legs	GETOL-RTP With Sea Legs
With Sea Legs		Without Sea Legs				
RTP	CF	RTP	CF			
						→ 500
200-250	400-450	200-250	400-450	225-450*	225	200-220
34,000	34,000	27,500	27,500	43,600	23,900**	61,000
						→ 5,000
10,700	10,700	9,740	9,740	17,440	9,560	15,400
4,900	4,900	3,940	3,940	11,640	3,760	9,600
						→ 4-800
14,120	16,540	9,940	11,540	13,080	6,880	25,060
5,360	3,730	4,440	3,380	9,680	5,880	15,070
3,730	3,030	3,380	2,840	3,400	1,580	5,470
.317	.317	.633	.633	.132	.409	.160
						→ 1
						→ 6
						→ 10

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TABLE 6

CANDIDATE AIR-SEA CRAFT VEHICLE CHARACTERISTICS AND PE

FOR

ONR MISSION PROFILE 1A

Air-Sea Craft Vehicle Characteristic	AIR-SEA CRAFT VEHICLE				
	Basic CTOL-TP	CTOL/STOL-TP		CTOL/ST	
		With Sea Legs	Without Sea Legs	With Sea Legs RTP	With Sea Legs CF
Mission Radius - n. mi.	500				
Cruise Velocity - Kn.	200-250			200-250	400-450
Takeoff Gross Weight-lbs.	40,000	55,000	44,500	45,000	45,000
Payload - lbs.	8,000				
Useful load - lbs	16,700	19,700	17,600	15,200	15,200
Fuel - lbs.	7,900	10,900	8,800	6,400	6,400
Crew Number and Weight - lbs.	4-800				
Airframe Weight - lbs.	12,820	21,190	14,490	18,170	21,150
Propulsion Weight - lbs.	4,660	6,350	5,380	6,860	4,770
Equipment Weight - lbs.	5,820	7,760	6,730	4,770	3,880
Cruise Efficiency - n. mi. /lb.$_{ave}$	.194	.141	.174	.239	.239
On Station Airborne Endurance - hrs.	1				
On Station Waterborne Endurance - hrs.	6				
Total Mission Duration - hrs.	10				

* Depending on type of air-sea craft vehicle design

TABLE 6

ARACTERISTICS AND PERFORMANCE SUMMARY
FOR
ION PROFILE 1A

-SEA CRAFT VEHICLE TYPES							
	CTOL/STOL-RTP and CF				VTOL-TP Sea Legs	Stopped Rotor VTOL-RTP Sea Legs	GETOL-RTP Sea Legs
out	With Sea Legs		Without Sea Legs				
egs	RTP	CF	RTP	CF			
							500
	200-250	400-450	200-250	400-450	225-450*	225	200-220
	45,000	45,000	37,300	37,300	66,100	36,300	74,500
							8,000
	15,200	15,200	14,100	14,100	26,440	14,520	20,500
	6,400	6,400	5,300	5,300	17,640	5,720	11,700
							4-800
	18,170	21,150	12,990	15,080	19,830	10,450	29,690
	6,860	4,770	5,800	4,410	14,680	8,930	17,830
	4,770	3,880	4,410	3,710	5,150	2,400	6,480
4	.239	.239	.289	.289	.087	.269	.131
							1
							6
							10

2

TABLE 7

CANDIDATE AIR-SEA CRAFT VEHICLE CHARACTERISTICS AND I

FOR

ONR MISSION PROFILE 2

Air-Sea Craft Vehicle Characteristic	AIR-SEA CRAFT VEHICL				
	Basic CTOL-TP	CTOL/STOL-TP With Sea Legs	CTOL/STOL-TP Without Sea Legs	CTOL/ With Sea Legs RTP	CTOL/ With Sea Legs CF
Mission Radius - n. mi.	1, 000				
Cruise Velocity - Kn.	200-250			200-250	400-4
Takeoff Gross Weight - lbs.	138, 000	219, 000	158, 000	137, 000	137, 0
Payload - lbs.	20, 000				
Useful Load - lbs.	72, 100	101, 000	79, 400	59, 000	59, 0
Fuel - lbs.	49, 700	78, 600	57, 000	36, 600	36, 6
Crew Number and Weight - lbs.	12-2400				
Airframe Weight - lbs.	36, 240	100, 300	60, 860	47, 600	55, 4
Propulsion Weight - lbs.	13, 180	30, 000	22, 140	17, 900	12, 5
Equipment Weight - lbs.	16, 480	36, 700	27, 700	12, 500	10, 1
Cruise Efficiency - n. mi. /lb_{ave}	. 0618	. 0389	. 0540	. 0843	. 08
On station Airborne Endurance - hrs.	3				
On Station Waterborne Endurance - hrs.	6				
Total Mission Duration - Hrs.	15				

Note: No VTOL-TP designs possible for mission profiles 2, 3, and 4 for assumed useful load-to-takeoff gross weight ratio and nautical miles per lb. of fuel data

TABLE 7

E CHARACTERISTICS AND PERFORMANCE SUMMARY

FOR

MISSION PROFILE ?

AIR-SEA CRAFT VEHICLE TYPES						
L-TP	CTOL/STOL-RTP and CF				Stopped Rotor VTOL-RTP With Sea Legs	GETOL-RTP With Sea Legs
Without	With Sea Legs		Without Sea Legs			
a Legs	RTP	CF	RTP	CF		
						1,000
	200-250	400-450	200-250	400-450	225	200-220
58,000	137,000	137,000	108,000	108,000	207,000	307,000
						20,000
79,400	59,000	59,000	51,200	51,200	82,800	112,000
57,000	36,600	36,600	28,800	28,800	61,400	89,600
						12-2400
60,860	47,600	55,400	31,800	36,900	59,500	107,300
22,140	17,900	12,500	14,200	10,800	51,000	64,300
27,700	12,500	10,100	10,800	9,100	13,700	23,400
.0540	.0843	.0843	.107	.107	.0509	.0343
						3
						6
						15

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TABLE 8

CANDIDATE AIR-SEA CRAFT VEHICLE CHARACTERISTICS AND

FOR

ONR MISSION PROFILE 3

Air-Sea Craft Vehicle Characteristic	AIR-SEA CRAFT VEHIC				
	Basic CTOL-TP	CTOL/STOL-TP		CTOI	
		With Sea Legs	Without Sea Legs	With Sea Legs RTP	CF
Mission Radius - n. mi.	1000				
Cruise Velocity - Kn.	200-250			200-250	400-4
Takeoff Gross Weight -lbs.	200,000	324,000	233,000	194,000	194,0
Payload - lbs.	30,000				
Useful Load - lbs.	109,600	157,000	122,300	88,300	88,3
Fuel - lbs.	76,800	124,200	89,500	55,500	55,5
Crew Number and Weight - lbs.	14-2800				
Airframe Weight - lbs.	49,720	100,300	60,860	64,500	75,1
Propulsion Weight - lbs.	18,080	30,000	22,140	24,300	16,9
Equipment Weight - lbs.	22,600	36,700	27,700	16,900	13,7
Cruise Efficiency - n mi. /lb. $_{ave}$	.0434	.0267	.0372	.0601	.06
On Station Airborne Endurance - hrs.	4				
On Station Waterborne Endurance - hrs.	20				
Total Mission Duration - Hrs.	30				

Note: No VTOL-TP designs possible for mission profiles 2, 3, and 4 for assumed useful load-to-takeoff gross weight ratio and nautical miles per lb. of fuel data

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TABLE 8

VEHICLE CHARACTERISTICS AND PERFORMANCE SUMMARY

FOR

ONR MISSION PROFILE 3

AIR-SEA CRAFT VEHICLE TYPES							
CTOL/STOL-TP		CTOL/STOL-RTP and CF				Stopped Rotor VTOL-RTP	GETOL-RTP
With Sea Legs	Without Sea Legs	With Sea Legs		Without Sea Legs		With Sea Legs	With Sea Legs
		RTP	CF	RTP	CF		
							1,000
		200-250	400-450	200-250	400-450	225	200-220
24,000	233,000	194,000	194,000	154,000	154,000	375,000	486,000
							30,000
57,000	122,300	88,300	88,300	76,800	76,800	150,000	185,000
24,200	89,500	55,500	55,500	44,000	44,000	117,200	152,200
							14-2800
00,300	60,860	64,500	75,100	43,200	50,200	107,900	165,600
30,000	22,140	24,300	16,900	19,300	14,700	92,300	99,300
36,700	27,700	16,900	13,700	14,700	12,300	24,800	36,100
.0267	.0372	.0601	.0601	.0757	.0757	.0284	.0219
							4
							20
							30

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TABLE 9

CANDIDATE AIR-SEA CRAFT VEHICLE CHARACTERISTICS AN

FOR

ONR MISSION PROFILE 4

Air-Sea Craft Vehicle Characteristic	AIR-SEA CRAFT VEH				
		CTOL/STOL-TP		CTOL	
	Basic CTOL-TP	With Sea Legs	Without Sea Legs	With Sea Legs RTP	C
Mission Radius - n. mi.	1000				
Cruise Velocity - Kn.	200-250			200-250	400-
Takeoff Gross Weight - lbs	276, 000	484, 000	320, 000	258, 000	258,
Payload - lbs.	38, 400				
Useful Load -lbs.	156, 200	242, 000	174, 500	122, 000	122,
Fuel - lbs.	113, 600	199, 400	131, 900	79, 400	79,
Crew Number and Weight - lbs	21-4200				
Airframe Weight - lbs.	65, 840	145, 200	80, 000	82, 900	96,
Propulsion Weight - lbs.	23, 960	43, 600	29, 100	31, 300	21,
Equipment Weight - lbs.	30, 000	53, 200	36, 400	21, 800	17,
Cruise Efficiency - n. mi. /lb.$_{ave}$	. 0320	. 0182	. 0276	. 0458	. C
On Station Airborne Endurance - hrs.	4				
On Station Waterborne Endurance - hrs	50				
Total Mission Duration - hrs.	60				

Note: No VTOL-TP designs possible for mission profiles 2, 3, and 4 for assumed useful load-to-takeoff gross weight ratio and nautical miles per lb. of fuel data

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TABLE 9

VEHICLE CHARACTERISTICS AND PERFORMANCE SUMMARY

FOR

ONR MISSION PROFILE 4

AIR-SEA CRAFT VEHICLE TYPES							
TOL/STOL-TP		CTOL/STOL-RTP and CF				Stopped Rotor VTOL-RTP Sea Legs	GETOL-RTP With Sea Legs
ith Legs	Without Sea Legs	With Sea Legs		Without Sea Legs			
		RTP	CF	RTP	CF		
							1000
		200-250	400-450	200-250	400-450	225	200-222
, 000	320, 000	258, 000	258, 000	203, 000	203, 000	666, 000	968, 000
							38, 400
, 000	174, 500	122, 000	122, 000	105, 000	105, 000	266, 400	368, 000
, 400	131, 900	79, 400	79, 400	62, 400	62, 400	223, 800	325, 000
							21-4200
5, 200	80, 000	82, 900	96, 500	54, 900	63, 700	191, 900	330, 000
3, 600	29, 100	31, 300	21, 800	24, 500	18, 600	163, 800	198, 000
3, 200	36, 400	21, 800	17, 700	18, 600	15, 700	43, 900	72, 000
.0182	.0276	.0458	.0458	.0582	.0582	.0162	.0112
							4
							50
							60

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2.1.2 Nonsensor Systems

The nonsensor systems carried by the air-sea craft consist of the following:

1. Avionics

   a. nonsonar system avionics
   b. sonobuoy system avionics

2. Weapons

The weights of these systems are summarized in Tables 10 through 13.

2.1.2.1 Avionics

The components of the avionics systems are listed below:

a. Nonsensor system avionics

   Navigation

   Pilot's subsystem

   Communications

   Nonsonar sensors

   Tactical coordinator system

b. Sonobuoy system avionics

   Operator display

   Sonobuoy receivers

   Passive alarm syetem

   JEZEBEL processor

   CASS processor

   Sensor reference position

   Recorder

The weights of these components are given in Table 10 for two types of systems: (1) a "core" system, and (2) a lightweight "core" system. The "core" system is suitable for mission profile 3 and 4 air-sea craft; this system has been reduced in number of components and in the weight of some components to form a lightweight "core" system suitable for mission profile 1, 1A, and 2 air-sea craft. The components and weights of the light and regular "core" systems are shown in Tables 11 and 12, respectively.

2.1.2.2 Weapons

The types of weapons carried by the air-sea craft and the weights of the weapon loads are presented in Table 13. In order to give the air-sea craft both nonnuclear and nuclear attack capability, two weapon types are selected: a Mk 46 homing torpedo and a Mk 101 atomic depth bomb. The numbers of torpedoes and depth bombs assigned to each mission profile air-sea craft are based on: (1) the air-sea craft payload for each mission profile, and (2) the number of attacks deemed reasonable for the size of the air-sea craft. The payloads of each mission profile air-sea craft are given in Tables 5 through 9. The number of attacks to which each type of air-sea craft should be able to respond is tabulated below.

MISSION PROFILE	NON-NUCLEAR TORPEDO ATTACKS **	ATOMIC DEPTH BOMB ATTACKS **
1 *	1-2	0
2	1-2	1
3	1-4	1
4	1-4	2

*Mission 1 air-sea craft could carry 1 depth bomb in lieu of 2 torpedoes for 1 nuclear attack. In each mission profile case, 1 atomic bomb and 2 MK 46 torpedoes are interchangeable.
**Assuming a single weapon is expended per attack.

TABLE 10

AIR-SEA CRAFT AVIONICS

NONSONAR SYSTEMS AVIONICS	MISSION PROFILE	
	1, 1A, AND 2 (LIGHTWEIGHT CORE SYSTEM)	3 AND 4 (CORE SYSTEM)
Navigation	230 lbs.	403 lbs.
Pilot's Subsystem	58	58
Communications	385	385
Nonsonar Sensors	474	1215
Tactical Coord. System	305	305
TOTAL	1452	2366
SONOBUOY SYSTEM AVIONICS		
Operator Display	100	100
Sonobuoy Receivers	100	100
Passive Alarm System	50	50
JEZEBEL Processor	80	80
CASS Buoy Processor	50	50
Sensor Reference Pos.	50	50
Recorder	60	60
Installation	73	73
TOTAL	563	563

TABLE 11

NON SONAR SYSTEM AVIONICS COMPONENTS

(LIGHTWEIGHT CORE SYSTEM)

COMPONENT		WEIGHT (lbs.)
Navigation System		
Autonavigator		50
Tacan		18
Loran C/Omega		20
Air Data		20
Heading Reference		20
Radar Altimeter		12
UHF DF/Dual VOR		30
LF ADF		20
BDH1		10
		200
Installation (15%)		30
	Subtotal	230
Pilot's Subsystem		
Pilot's Display and controls		50
Installation (15%)		8
	Subtotal	58
Communications System		
HF SSB (Transmitter)		50
HF SSB (Receiver)		20
UHF Data Link		50
UHF/VHF Communications		60

TABLE 11 (contd)

NON SONAR SYSTEM AVIONICS COMPONENTS
(LIGHTWEIGHT CORE SYSTEM)
Continued

COMPONENT		WEIGHT (lbs.)
Communications System Cont'd.		
ICS		15
IFF Interrogator		15
IFF Transponder		30
Sonar Data Relay		15
Teletype		80
		335
Installation (15%)		50
	Subtotal	385
Non Sonar Sensor Systems		
Scanning Radar (180°)		212
ECM		100
Magnetic Anomaly Detector		100
		412
Installation (15%)		62
	Subtotal	474
Tactical Coordinator's System		
Displays and Controls		200
Digital Data Processor		65
		265
Installation (15%)		40
	Subtotal	305
	Total all Components	1452

TABLE 12

NON SONAR SYSTEM AVIONICS COMPONENTS
(CORE SYSTEM)

COMPONENT		WEIGHT (lbs.)
Navigation System		
Autonavigator		50
Tacan		18
Loran C/Omega		20
Air Data		20
Heading Reference		20
Radar Altimeter		12
UHF DF/Dual VOR		30
LF ADF		20
BDHI		10
Installation		30
Stellar Monitor*		85
Doppler Radar*		65
Installation*		23
	Subtotal	403
Pilot's Subsystems		
Pilot's Display and Controls		50
Installation		8
	Subtotal	58

*Components of Core System not in Lightweight Core System

TABLE 12 (contd)

NON SONAR SYSTEM AVIONICS COMPONENTS
(CORE SYSTEM)
Continued

COMPONENT	WEIGHT (lbs.)
Communication System	
HF SSB (Transmitter)	50
HF SSB (Receiver)	20
UHF Data Link	50
UHF/VHF Communications	60
ICS	15
IFF Interrogator	15
IFF Transponder	30
Sonar Data Relay	15
Teletype	80
Installation	50
Subtotal	385
Nonsonar Sensor Systems	
Scanning Radar (180°)	212
ECM	100
Magnetic Anomaly Detector	100
Installation	62
Additional Radar for 360° Scan*	200
Infrared*	100
Condensation Nuclei Detector (Trail)*	45
Low Level Flight Television*	50
Photographic*	100
ECM (Additional)*	150
Installation	96
Subtotal	1215

* Components of Core System not in Lightweight Core System

TABLE 12 (contd)

NONSONAR SYSTEM AVIONICS COMPONENTS
(CORE SYSTEM)
Continued

COMPONENT		WEIGHT (lbs.)
Tactical Coordinator's System		
Displays and Controls		200
Digital Data Processor		65
Installation		45
	Subtotal	305
	Total all Components	2366

TABLE 13

AIR-SEA CRAFT WEAPONS

WEAPONS	MISSION PROFILE			
	1	2	3	4
MK46 TORPEDO				
Number	2	2	4	4
Weight (lbs.)	1140	1140	2280	2280
MK101 DEPTH CHARGE				
Number	0	1	1	2
Weight (lbs.)	0	1200	1200	2400
TOTAL WEIGHT (lbs.)	1140	2340	3480	4680

2.1.3 Sensor Systems

The sensor systems are composed of:

1. Sonar systems
2. Expendable sonobuoys

The weights of the various types of sonar systems are shown in Table 14; those of the expendable sonobuoys in Table 15.

2.1.3.1 Sonar Systems

The types of sonar systems employed in the air-sea craft for all mission profiles are:

Dipped sonar
- light weight
- medium weight

Towed sonar

Retrievable buoys (ATSSS-type)
- passive mode
  - light weight
  - heavy weight
- active mode
  - heavy weight

The detection capability of each sonar system is an important parameter in forming candidate air-sea craft systems for the operational analyses. This capability is referenced in Table 14. No data are presented in the table because detection capability is a function of many factors other than sonar system characteristics: target radiated noise (in the case of passive detection), target strength (in the case of active detection), sea state, transducer depth, towing speed, etc. For a full presentation of the relevant factors in each sonar system and the resulting detection capability, refer to the Figures and Tables cited (in Table 14) from Volume IV, Part II, Acoustic Sensor System Characteristics, Performance, and Technical Feasibility.

2.1.3.2 Expendable Sonobuoys

Two types of expendable sonobuoys are selected to provide additional localization, classification, and attack capability. They are CASS sonobuoys, which are active, and JEZEBEL buoys, which are passive. The numbers assigned to each mission profile air-sea craft are based on: (1) the requirements for localization patterns and (2) the payload remaining after avionics, weapons, and sonar systems are accounted for. These numbers and the associated weights are shown in Table 15.

2.2 Air-Sea Craft Candidate Systems

2.2.1 Potential Candidate Systems

The initial step taken in determining candidate air-sea craft systems was to enumerate the various potential configurations of air-sea craft systems. The three main determinants of an air-sea craft system are:

1. The mission profile
2. The dipped sonar system weight alternatives
3. The retrievable buoy mixture employed operationally.

The number of potential candidate systems is equal to the product of the numbers of mission profiles, buoy mixtures, and dipped sonar weights. These numbers are:

1. Mission profiles - there are four: 1, 2, 3, 4
2. Dipped sonar weights - there are three: 1150, 3415, and 10,600*
3. Retrievable buoy mixtures - there are three:
   a. 100% passive buoys
   b. 80% passive plus 20% active buoys
   c. 100% active buoys

*In mission profiles 1 and 4 some candidate systems use no dipped sonar, so the weight in these cases is 0.

TABLE 14

SONAR SYSTEMS

Sonar Type	Sonar Weight (lbs.)	Detection Capability
Dipped Sonar		
Light	1150	See Figure 24 of Vol. IV
Heavy	3415	
Towed Sonar	1000	See Figure 38 of Vol. IV
Retrievable Buoy		
Passive		
Light	1000	See Tables 32-35 and Figures 42, 43 of Vol. IV
Heavy	1800	
Active	4000 for 1 Buoy 3500 each for > 1 Buoy	See Table 38 and Figure 45 of Vol. IV

TABLE 15

AIR-SEA CRAFT EXPENDABLE SONOBUOYS

SONOBUOYS	MISSION PROFILE			
	1 and 1A	2	3	4
CASS*				
Number	9	9	18	21
Weight (lbs.)	315	315	630	735
JEZEBEL*				
Number	19	19	38	44
Weight (lbs.)	380	380	760	880
MARKERS*				
Number	28	28	56	65
Weight (lbs.)	56	56	112	130
TOTAL WEIGHT	751	751	1502	1745

*The same number of expendable sonobuoys and markers has been included for Mission Profiles 1 and 1A, and 2 air-sea craft although the on-station air search endurance is 3 times greater for Mission Profile 2 than for Mission Profile 1 and 1A and the number of takeoffs and landings is 2.6 times greater, as shown on Table 4. The best estimate of the CAL project group is that the number of expendable sonobuoys and markers included for the Mission Profile 2 air-sea craft is adequate, based on available on-station airborne endurance, while the same number designated for Mission Profile 1 and 1A air-sea craft is deemed excessive. Nevertheless, the extra sonobuoys and markers have been included in the Mission Profile 1 and 1A air-sea craft in order to round out their payload weights to maximum allowable capacity.

The total number of potential candidate system combinations is then given below for each mission profile.

MISSION PROFILE	NUMBER OF DIPPED SONAR WEIGHTS	NUMBER OF RETRIEVABLE BUOY MIXTURES	TOTAL NUMBER OF CANDIDATE SYSTEMS
1	3	2	4*
2	2	3	6
3	3	3	9
4	4 **	3	12

The potential candidate systems are summarized in Tables 16 through 19. Mission profile 1 candidate systems appear in Table 16, mission 2 in Table 17, mission 3 in Table 18, and mission 4 in Table 19. In each case, the following data on the candidate system are given:

1. Allowed payload
2. Sonar system employed
3. Allowed sonar system weight
4. Actual sonar system weight
5. Weight of nonsonar systems
6. Actual payload

Within the same mission profile, any one of the potential candidate sensor suits listed in Tables 16 through 19 can be incorporated into the payload of any of the generic types of air-sea craft listed in Tables 5 through 9.

---

* Mission profile No. 1 is the smallest payload vehicle; it can accept only dipped sonar weights of 0, 1150, and 3415 lbs. Not all buoy mixtures can be used with these dipped sonar weights, hence there are less than 6 candidate systems.

** Four dipped sonar weights are considered: 0, 1150, 3415, and 10,600 lbs.

2.2.2 Selected Candidate Systems

At this point in the study of the candidate systems, the operational analysis of the various ASW missions was begun. The missions are: passive barrier operations, task group screening (versus long-range and short-range threats), convoy protection, contact area investigation, and localization and attack. These analyses are described fully in Volume VI of this report.

The ASW missions analyses determined the capabilities required of air-sea craft systems in carrying out each mission. These requirements were then matched as closely as possible with air-sea candidate systems capabilities in the list of potential candidate systems (Tables 16 through 19). The requirements include:

Vehicle operating radius

Vehicle endurance

a. airborne

b. waterborne

Vehicle payload

Type of sonar system required (dipped, towed, retrievable buoy)

Sonar detection range

Retrievable buoy

a. detection range

b. buoy mixture

The result of this matching process is a set of selected candidate systems which would be capable of performing the required missions. Not every candidate system selected is appropriate for every mission analyzed, however. Table 20 shows the selected air-sea craft candidate systems with their associated sonar systems and the missions they are capable of carrying out. The number of selected candidate systems in mission profile 1 is two; in mission profile 2 is two; in mission profile 3 is three; and in mission profile 4, is four. Thus there are eleven selected candidate systems.

Any of the generic types of air-sea craft listed in Tables 5 through 9 which have the same payload as selected candidate systems of Table 20 can perform the same ASW mission (s) with the sensor suites.

TABLE 16

SONAR SYSTEMS FOR CANDIDATE AIR-SEA CRAFT VEHICLES
MISSION PROFILE NO. 1 AND 1A

	MISSION PROFILE NO.			
	1	1A	1A	1A
Air-Sea Craft System	1A	1B	1C	1D
Allowed Payload	5000	8000	8000	8000
Sonar System				
Dipped	1150	0	3415	0
Towed	0	0	1000	0
Retrievable Buoys: Buoy Mixture	No Buoys	100% Passive	No Buoys	100% Active
Light Passive/Active* (1000 lbs) (4000 lbs)	0L/0A	4L/0A 4000/0	0L/0A	0L/1A 0/4000
or Heavy Passive/Active* (1800 lbs) (4000 lbs)	0H/0A	2H/0A 3600/0	0H/0A	0H/1A 0/4000
Allowed Sonar System Weight	1094	4094	4094	4094
Actual Sonar System Weight	1150	L:4000 H:3600	4415	4000
Weight of Non-Sonar Packages (Avionics, Weapons, etc.)	3906	3906	3906	3906
Actual Air-Sea Craft Payload	5056	L:7906 H:7506	8321	7906

*A single active buoy weighs 4000 lbs.; two or more buoys weigh 3500 lbs. each.

TABLE 17

SONAR SYSTEM FOR CANDIDATE AIR-SEA CRAFT VEHICLES

MISSION PROFILE NO. 2

Air-Sea Craft System	2A1	2A2	2A3	2B1	2B2	2B3
Allowed Payload	20,000	20,000	20,000	20,000	20,000	20,000
Sonar System	1,150	1,150	1,150	3,415	3,415	3,415
Dipped						
Towed	1,000	1,000	1,000	1,000	1,000	1,000
Retrievable Buoys Buoy Mixture Light Passive/Active * (1000 lbs) (4000 lbs)*	100% Passive 13L/0A 13,000/0	80%P+20%A 9L/1A 9000/4000	100% Active 0L/4A 0/14,000	100% Passive 11L/0A 11,000/0	80%P+20%A 7L/1A 7000/4000	100% Active 0L/3A 0/10,500
or Heavy Passive/Active * (1800 lbs) (4000lbs)*	7H/0A 12,600/0	5H/1A 9000/4000	0H/4A 0/14,000	6H/0A 10,800/0	4H/1A 7200/4000	0H/3A 0/10,5000
Allowed Sonar System Weight	14,896	14,896	14,896	14,896	14,896	14,896
Active Sonar System Weight	L:15,150 H:14,750	L:15,150 H:15,150	16,150	L:15,416 H:15,215	L:15,415 H:15,615	14,915
Weight of Nonsonar Packages (Avionics, Weapons, Etc.)	5,106	5,106	5,106	5,106	5,106	5,106
Actual Air-Sea Craft Payload	L:20,256 H:19,856	L:20,256 H:20,256	21,256	L:20,522 H:20,321	L:20,521 H:20,721	20,021

*A single active buoy weighs 4000 lbs.; two or more buoys weigh 3500 lbs. each.

TABLE 18

SONAR SYSTEMS FOR CANDIDATE AIR-SEA CRAF

MISSION PROFILE NO. 3

Air-Sea Craft System	3A1	3A2	3A3	3B1	
Allowed Payload	30,000	30,000	30,000	30,000	30
Sonar System					
Dipped	1,150	1,150	1,150	3,415	3
Towed	1,000	1,000	1,000	1,000	1
Retrievable Buoys					
Buoy Mixture	100% Passive	80%P+20%A	100% Active	100% Passive	80'
Light Passive/Active *	20L/0A	13L/2A	0L/6A	18L/0A	11]
(1000 lbs) (4000 lbs)*	20,000/0	13,000/7000	0/21,000	18,000/0	11,
or					
Heavy Passive/Active *	11H/0A	7H/2A	0H/0A	10H/0A	6H
(1800 lbs) (4000 lbs)*	19,800/0	12,600/7000	0/21,000	18,000/0	10,
Allowed Sonar System Weight	22,089	22,089	22,089	22,089	22
Active Sonar System Weight	L:22,150	L:22,150	23,150	L:22,415	L:
	H:21,950	H:21,750		H:22,415	H,
Weight of Non-Sonar Packages	7,911	7,911	7,911	7,911	7
(Avionics, Weapons, Etc.)					
Actual Air-Sea Craft Payload	L:30,061	L:30,061	31,061	L:30,326	L:
	H:29,861	H:29,661		H:30,326	H:

*A single active buoy weighs 4000 lbs.; two or more buoys weigh 3500 lbs. each.

TABLE 18

CANDIDATE AIR-SEA CRAFT VEHICLES
SSION PROFILE NO. 3

A3	3B1	3B2	3B3	3C1	3C2	3C3
000	30,000	30,000	30,000	30,000	30,000	30,000
150	3,415	3,415	3,415	10,600	10,600	10,600
000	1,000	1,000	1,000	1,000	1,000	1,000
Active	100% Passive	80%P+20%A	100% Active	100% Passive	80%P+20%A	100% Active
A	18L/0A	11L/2A	0L/5A	10L/0A	7L/1A	0L/3A
1,000	18,000/0	11,000/7000	0/17,500	10,000/0	7000/4000	0/10,500
6A	10H/0A	6H/2A	0H/5A	6H/0A	4H/1A	0H/3A
1,000	18,000/0	10,800/7000	0/17,500	10,800/0	7200/4000	0/10,500
089	22,089	22,089	22,089	22,089	22,089	22,089
150	L:22,415	L:22,415	21,915	L:21,600	L:22,600	22,100
	H:22,415	H, 22,215		H:2[illegible],400	H:22,800	
911	7,911	7,911	7,911	7,911	7,911	7,911
061	L:30,326	L:30,326	29,826	L:29,511	L:30,511	30,011
	H:30,326	H:30,126		H:30,311	H:30,711	

3500 lbs. each.

TABLE 19

SONAR SYSTEMS FOR CANDIDATE .

MISSION PROFILE N(

Air-Sea Craft System	4A1	4A2	4A3	4B1	4B2	4
Allowed Payload	38,400	38,400	38,400	38,400	38,400	38,
Sonar System						
Dipped	1150	1150	1150	3415	3415	34
Towed	1000	1000	1000	1000	1000	10(
Retrievable Buoys						
Buoy Mixture	100% Pass.	80%P+20%A	100% Act.	100% Pass.	80%P+20%A	10
Light Passive/Active* (1000 lbs) (4000 lbs)	27L/0A 27,000/0	16L/3A 16,000/10,500	0L/8A 0/28,000	25L/0A 25,000/0	14L/3A 14,000/10,500	0L 0/
or						
Heavy Passive/Active* (1800 lbs) (4000 lbs)	15H/0A 27,000/0	11H/2A 19,800/7000	0H/8A 0/28,000	14H/0A 25,200/0	10H/2A 18,000/7000	0H 0/
Allowed Sonar System Weight	29,046	29,046	29,046	29,046	29,046	29,
Actual Sonar System Weight	L:29,150 H:29,150	L:28,650 H:28,950	30,150	L:29,415 H:29,615	L:28,915 H:29,415	28,
Weight of Non-Sonar Packages (Avionics, Weapons, Etc.)	9354	9354	9354	9354	9354	93!
Active Air-Sea Craft Payload	L:38,504 H:38,504	L:38,004 H:38,304	39,504	L:38,769 H:38,969	L:38,269 H:38,769	38,

*A single active buoy weighs 4000 lbs.; two or more buoys weigh 3500 lbs. each.

TABLE 19

CANDIDATE AIR-SEA VEHICLES
N PROFILE NO. 4

4B2	4B3	4C1	4C2	4C3	4D1	4D2	4D3
8,400	38,400	38,400	38,400	38,400	38,400	38,400	38,400
415	3415	10,600	10,600	10,600	--	--	--
000	1000	1000	1000	1000	1000	1000	1000
%P+20%A	100% Act.	100% Pass.	80%P+20%A	100% Act.	100% Pass.	80%P+20%A	100% Act.
L/3A ,000/10,500	0L/7A 0/24,500	18L/0A 18,000/0	10L/2A 10,000/7000	0L/5A 0/17,500	28L/0A 28,000/0	22L/2A 22,000/7000	0L/8A 0/28,000
H/2A ,000/7000	0H/7A 0/24,500	10H/0A 18,000/0	6H/2A 10,800/7000	0H/5A 0/17,500	16H/0A 28,800/0	12H/2A 21,600/7000	0H/8A 0/28,000
9,046	29,046	29,046	29,046	29,046	29,046	29,046	29,046
:28,915 :29,415	28,915	L:29,600 H:29,600	L:28,600 H:29,400	29,100	L:29,000 H:29,800	L:30,000 H:29,600	29,000
354	9354	9354	9354	9354	9354	9354	9354
:38,269 :38,769	38,269	L:38,954 H:38,954	L:37,954 H:38,754	38,454	L:38,354 H:39,154	L:39,354 H:38,954	38,354

each.

TABLE 20

SELECTED AIR-SEA CRAFT CAND

SONAR SYSTEMS	AIR-				
	1B	1C	1D	2B2	2B3
ASW MISSION*	B.C	B.S.L.C.T.	S.L.C	B.L.C.T.	S.L.C.T
Allowed Sonar Weight (lbs)	4,094	4,094	4,094	14,896	14,896
Dipped Sonar	0	3,415	0	3,415	3,415
Towed Sonar	0	1,000	0	1,000	1,000
Retrievable Buoys					
Buoy Mixture	100% Passive	No Buoys	100% Act	80%P+20%A	100% Ac
Light Passive/Active	4L/0A	0L/0A	0L/1A	7L/1A	0L/3A
(1000 lbs) (4000 lbs)**	4000/0		0/4000	7000/4000	0/10,50
or					
Heavy Passive/Active	2H/0A	0H/0A	0H/1A	4H/1A	0H/3A
(1800 lbs) (4000 lbs)**	3600/0		0/4000	7200/4000	0/10,50
Total Sonar Weight for Systems Incorporating:					
Light Passive Buoys	4000			15,415	
Heavy Passive Buoys	3600			15,615	
Active Buoys			4000		14,915
Other Sonars		4415			

*ASW MISSIONS: B = Barrier Operations
S = Task Group or Convoy Screening
C = Contact Area Investigation
L = Localization and Attack
T = Trailing Operations

**A single active retrievable buoy weighs 4000 lbs.; two or more buoys weigh 3500 lbs. each.

ABLE 20

RAFT CANDIDATE SYSTEMS

	AIR-SEA CRAFT CANDIDATE SYSTEMS							
	2B3	3A2	3B2	3B3	4A2	4B2	4B3	4D2
	S.L.C.T.	B.L.C.	B.L.T.	B.S.L.C.	B.L.	B.L.T.	S.L.C.	B.L.C.
	14,896	22,089	22,089	22,089	29,046	29,046	29,046	29,046
	3,415	1,150	3,415	3,415	1,150	3,415	3,415	0
	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
A	100% Act	80%P+20%A	80%P+20%A	100% Act	80%P+20%A	80%P+20%A	100% Act.	80%P+20%A
	0L/3A	13L/2A	11L/2A	0L/5A	16L/3A	14L/3A	0L/7A	22L/2A
	0/10,500	13,000/7000	11,000/7000	0/17,500	16,000/10,500	14,000/10,500	0/24,500	22,000/7000
	0H/3A	7H/2A	6H/2A	0H/5A	11H/2A	10H/2A	0H/7A	12H/2A
	0/10,500	12,600/7000	10,800/7000	0/17,500	19,800/7000	18,000/7000	0/24,500	21,600/7000
		22,150	22,415		28,650	28,915		30,000
		22,215	22,215		28,950	29,415		29,600
	14,915			21,915			28,915	

2

0 lbs. each.

1.0 AIR-SEA CRAFT COST FACTORS

1.1 Introduction

Initial investment and annual operating costs are estimated for the candidate air-sea craft systems which are considered for the performance of each of the ASW missions. All costs are expressed in 1960 dollars.

The air-sea craft systems examined are shown in Table 21. All air-sea craft carry the same total sensor and avionics payload for a particular mission profile.

TABLE 21

CANDIDATE AIR-SEA CRAFT SYSTEMS

Air-Sea Craft Configuration	Propulsion System	Sealegs	Speed (Kts)	ONR Mission Profile
CTOL	TP*	yes	200-250	All
STOL	TP	"	"	"
CTOL	RTP**	"	"	"
STOL	RTP	"	"	"
CTOL	CF***	"	400-450	"
VTOL	RTP	"	"	Mission Profile 1 & 1A only
SR/VTOL	RTP	"	"	All
CTOL	TP	no	200-250	All
STOL	TP	"	"	"
CTOL	RTP	"	"	"
STOL	RTP	"	"	"
CTOL	CF	"	400-450	"
CTOL****	TP	"	200-250	"

*TP = Turbo Prop
**RTP = Regenerative Turbo Prop
***CF = Cruise Fan
****Basic CTOL configuration without hydroski, boundary layer control, or sealegs

CTOL - Conventional takeoff and landing design
STOL - Short takeoff and landing design with boundary layer control and hydroski
SR/VTOL - Stopped rotor vertical takeoff and landing design

1.2 Cost Methodology

Air-sea craft system initial investment costs, annual operating costs, and costs per sortie are derived in this section. These are subsequently used in the cost-effectiveness evaluations of candidate air-sea craft. The cost factors employed are derived utilizing References 1, 2, 3 and 4.

2.0 INITIAL INVESTMENT COSTS

The initial investment cost factors in dollars per pound for airframe/propulsion systems and avionics/electronics systems as a function of the number of the various types of air-sea craft procured are shown in Figure 17. The initial investment cost factors for special support equipment, spares and air-sea craft payload are summarized in Table 22.

TABLE 22

INITIAL INVESTMENT COST FACTORS FOR SPECIAL SUPPORT EQUIPMENT, SPARES, AND AIR-SEA CRAFT PAYLOAD

Item	Cost Factor
Special Support Equipment	10% of initial investment cost less spares and payload
Spares	
Airframe	16% of initial investment cost
Engine	90% of initial investment cost
Avionics and Electronics	75% of initial investment cost
Payload	
Retrievable Sonobuoys	$50/lb.
Weapons, Markers, etc.	Based on actual items carried

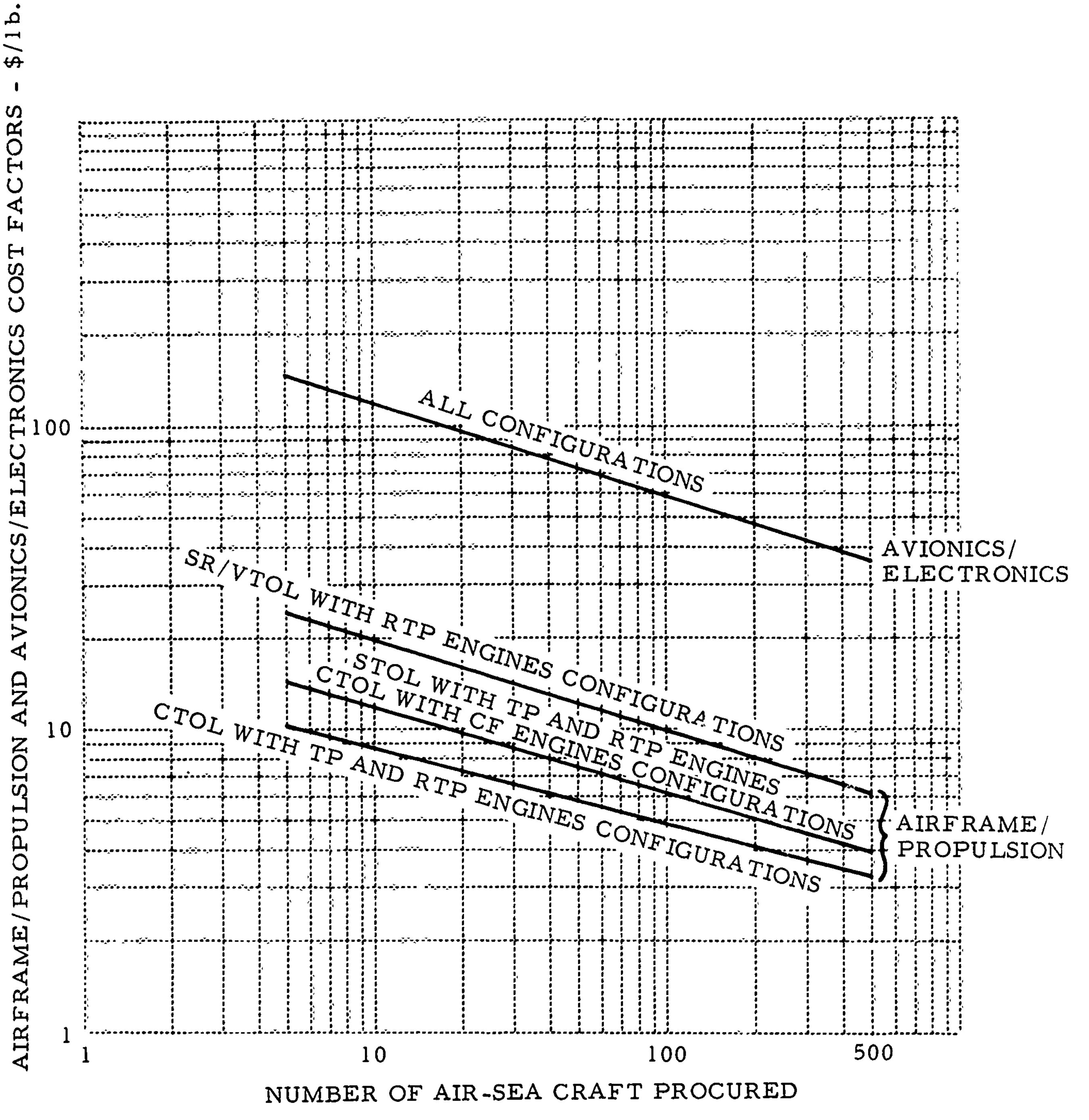

Figure 17 AIRFRAME/PROPULSION AND AVIONICS/ELECTRONICS COST FACTORS VS NUMBER OF AIR-SEA CRAFT PROCURED

The cost factor-procurement quantity relationships shown in Figure 17 for airframe/propulsion systems and avionics/electronics systems assume the 81% learning rate which is typical for most U. S. Navy fixed-wing aircraft. Air-sea craft payloads are treated as government furnished equipment (GFE) which are provided at a fixed cost irrespective of quantity. No distinction is made in the cost factors between aircraft equipped with TP and RTP propulsion systems, since engine development costs would not be charged to a particular aircraft program. STOL cost factors are applied to the CTOL aircraft equipped with CF-type engines because of the speed differential. Both the 200-250 and 400-450 knot aircraft appear well within the state-of-the-art with respect to speed and a larger cost difference does not appear warranted.

The initial investment costs do not include avionics and electronics systems R& D costs. The development of avionics and sensor equipment capabilities considered in this study is estimated to cost from $5 - $15 million, depending on the specific types selected. The cumulative average initial investment costs of the candidate air-sea craft based on production quantities of 100 units are shown in Tables 23 through 26. Average S/CTOL and SR/VTOL initial investment costs as related to the four mission profiles are shown at the bottom of the tables. Also, air-sea craft payload costs are noted for each mission profile.

For each air-sea craft configuration and associated ONR mission profile, the initial investment costs fall into a relatively narrow range with the exception of SR/VTOL - type air-sea craft. The latter are always the most costly. The use of regenerative turboprop engines always results in smaller and lower cost air-sea craft compared to similar air-sea craft equipped with turboprop engines. Total initial investment costs (less cost of payload) based on average S/CTOL and SR/VTOL costs for each air-sea craft configuration and associated ONR mission profile are plotted as a function of the quantity procured in Figure 18.

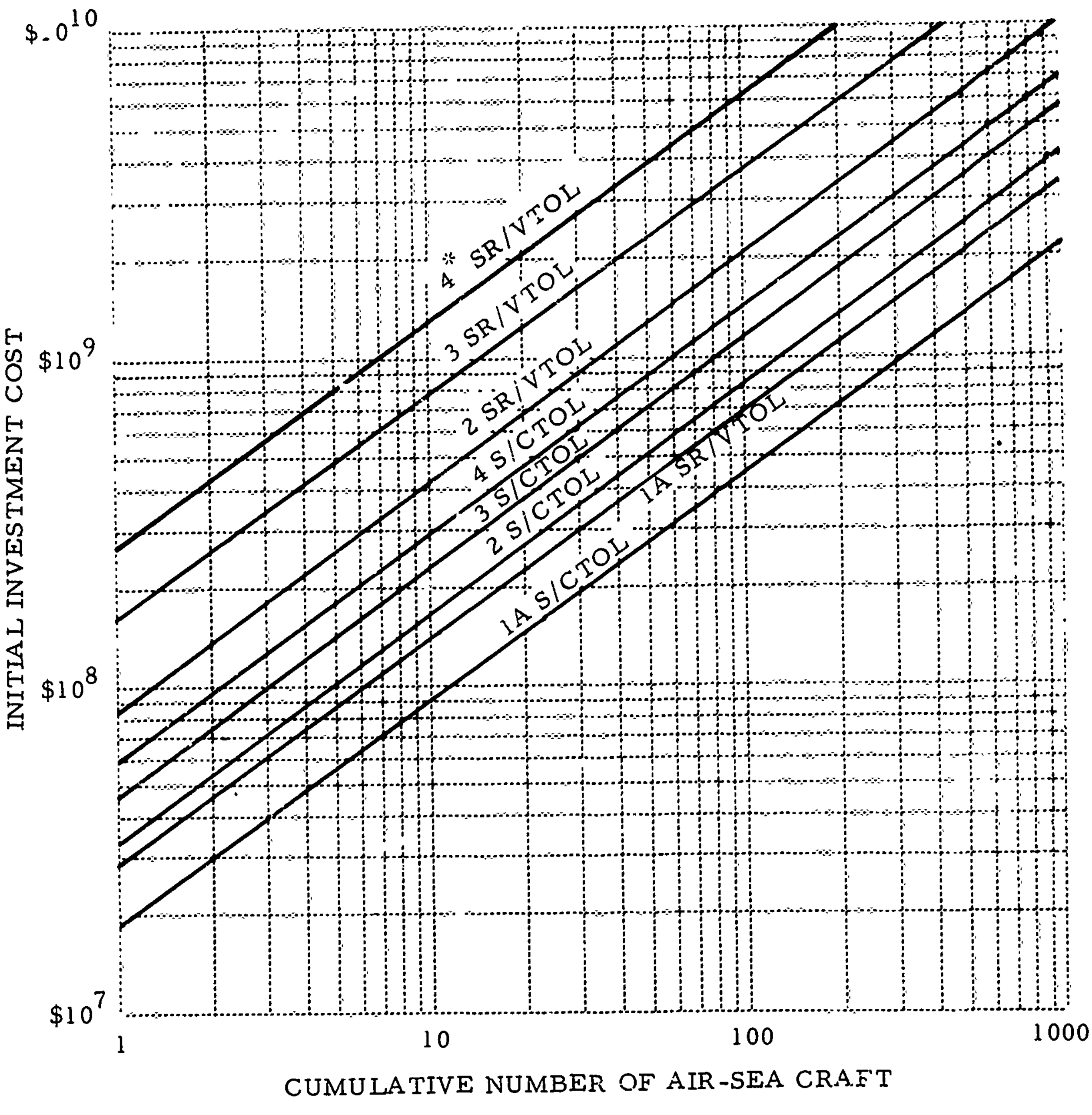

Figure 18 AIR-SEA CRAFT INITIAL INVESTMENT COST (LESS PAYLOAD) VERSUS NUMBER OF AIR-SEA CRAFT PROCURED

Costs based on average S/CTOL and SR/VTOL costs

*Mission Profiles 1A, 2, 3 and 4

TABLE 23

SINGLE AIR-SEA CRAFT INITIAL INVESTMENT COST

MISSION PROFILE 1A AIR-SEA CRAFT

Based on a Production Quantity of 100 Units—Cost in $ Millions

Air-Sea Craft Configuration	Type of Engine	Sea Legs	Airframe and Equipment	Propulsion	Avionics and Electronics	Spares	Supporting Equipment	Initial Investment Cost
CTOL	TP	yes	1.4	.3	1.2	1.4	.3	4.6
STOL	TP	yes	1.8	.4	1.2	1.5	.3	5.2
CTOL	RTP	yes	1.1	.3	1.2	1.3	.3	4.2
STOL	RTP	yes	1.4	.4	1.2	1.5	.3	4.8
CTOL	CF	yes	1.5	.3	1.2	1.4	.3	4.7
SR/VTOL	RTP	yes	1.2	.9	1.2	1.9	.3	5.5*
UTOL	RTP	yes	2.4	1.4	1.2	2.5	.5	8.0*
CTOL	TP	no	1.0	.3	1.2	1.3	.3	4.1
STOL	TP	no	1.3	.4	1.2	1.5	.3	4.7
CTOL	RTP	no	.8	.3	1.2	1.3	.2	3.8
STOL	RTP	no	1.1	.4	1.2	1.4	.3	4.4
CTOL	CF	no	1.1	.3	1.2	1.3	.3	4.2
CTOL	TP**	no	.9	.2	1.2	1.2	.2	3.7

AVERAGE AIR-SEA CRAFT INITIAL INVESTMENT COST

Air-Sea Craft Configuration	Less Payload	With Payload
S/CTOL	4.4	4.8
SR/VTOL	6.8	7.2

Payload	Payload Cost
Retrievable Buoys	0.2
Weapons, Expendable Buoys, Markers	0.2
Total	0.4

* The aircraft costs appear low. Aircraft designs are questionable because they are based n large extrapolations of UL/TOGW and n. mi./lb. data.

**No sea legs, boundary layer control or hydroski systems.

TABLE 24

SINGLE AIR-SEA CRAFT INITIAL INVESTMENT COST

MISSION PROFILE 2 AIR-SEA CRAFT

Based on a Production Quantity of 100 Units - Cost in $Millions

Air-Sea Craft Configuration	Type of Engine	Sea Legs	Airframe and Equipment	Propulsion	Avionics and Electronics	Spares	Supporting Equipment	Initial Investment Cost
CTOL	TP	yes	4.5	1.0	1.2	2.5	.7	9.9
STOL	TP	yes	5.7	1.2	1.2	2.9	.8	11.8
CTOL	RTP	yes	2.9	.9	1.2	2.2	.5	7.7
STOL	RTP	yes	3.6	1.0	1.2	2.4	.6	8.8
CTOL	CF	yes	3.9	.8	1.2	2.2	.6	8.7
SR/VTOL	RTP	yes	6.9	4.8	1.2	6.3	1.3	20.5
VTOL	RTP	yes	NA	NA	NA	NA	NA	NA
CTOL	TP	no	3.0	.8	1.2	2.1	.5	7.6
STOL	TP	no	3.7	.9	1.2	2.3	.6	8.7
CTOL	RTP	no	2.0	.6	1.2	1.8	.4	6.0
STOL	RTP	no	2.5	.8	1.2	2.0	.5	7.0
CTOL	CF	no	2.7	.7	1.2	2.0	.5	7.1
CTOL	TP*	no	2.5	.6	1.2	1.8	.4	6.5

AVERAGE AIR-SEA CRAFT INITIAL INVESTMENT COST

Air-Sea Craft Configuration	Less Payload	With Payload
S/CTOL	8.2	9.3
SR/VTOL	20.5	21.6

Payload	Payload Cost
Retrievable Buoys	0.8
Weapons, Expendable Buoys, Markers	0.3
Total	1.1

NA Not applicable

* No sea legs, boundary layer control or hydroski systems

TABLE 25

SINGLE AIR-SEA CRAFT INITIAL INVESTMENT COST

MISSION PROFILE 3 AIR-SEA CRAFT

Based on a Production Quantity of 100 Units - Cost in $ Millions

Air-Sea Craft Configur-ation	Type of Engine	Sea Legs	Airframe and Equipment	Propul-sion	Avionics and Electronics	Spares	Supporting Equipment	Initial Investment Cost
CTOL	TP	yes	6.5	1.4	1.7	3.6	1.0	14.2
STOL	TP	yes	8.3	1.8	1.7	4.2	1.2	17.2
CTOL	RTP	yes	3.9	1.1	1.7	2.9	.7	10.3
STOL	RTP	yes	4.8	1.4	1.7	3.3	.8	12.0
CTOL	CF	yes	5.3	1.0	1.7	3.0	.8	11.8
SR/VTOL	RTP	yes	13.0	9.0	1.7	11.4	2.4	37.5
VTOL	RTP	yes	NA	NA	NA	NA	NA	NA
CTOL	TP	no	4.2	1.0	1.7	2.3	.7	10.4
STOL	TP	no	5.2	1.3	1.7	3.3	.8	12.3
CTOL	RTP	no	2.8	.9	1.7	2.5	.5	8.4
STOL	RTP	no	3.5	1.1	1.7	2.8	.6	9.7
CTOL	CF	no	3.7	.9	1.7	2.7	.6	9.6
CTOL	TP*	no	3.4	.9	1.7	2.6	.6	9.2

AVERAGE AIR-SEA CRAFT INITIAL INVESTMENT COST		
Air-Sea Craft Configuration	Less Payload	With Payload
S/CTOL	11.4	12.8
SR/VTOL	37.5	38.9

Payload	Payload Cost
Retrievable Buoys	1.1
Weapons, Expendable Buoys, Markers	0.3
Total	1.4

NA Not applicable

* No sea legs, boundary layer control or hydroski systems

TABLE 26

SINGLE AIR-SEA CRAFT INITIAL INVESTMENT COST

MISSION PROFILE 4 AIR-SEA CRAFT

Based on a Production Quantity of 100 units - Cost in $ Millions

Air-Sea Craft Configuration	Type of Engine	Sea Legs	Airframe and Equipment	Propulsion	Avionics and Electronics	Spares	Supporting Equipment	Initial Investment Cost
CTOL	TP	yes	9.4	2.1	1.7	4.7	1.3	19.2
STOL	TP	yes	12.1	2.6	1.7	5.6	1.6	23.6
CTOL	RTP	yes	5.0	1.5	1.7	3.4	.8	12.4
STOL	RTP	yes	6.2	1.9	1.7	4.0	1.0	14.8
CTOL	CF	yes	6.8	1.3	1.7	3.5	1.0	14.3
SR/VTOL	RTP	yes	22.4	15.6	1.7	18.9	4.0	62.6
VTOL	RTP	yes	NA	NA	NA	NA	NA	NA
CTOL	TP	no	5.6	1.4	1.7	3.4	.8	12.9
STOL	TP	no	7.1	1.7	1.7	3.9	1.0	15.4
CTOL	RTP	no	3.5	1.2	1.7	2.9	.6	9.9
STOL	RTP	no	4.4	1.5	1.7	3.3	.8	11.7
CTOL	CF	no	4.7	1.1	1.7	3.0	.8	11.3
CTOL	TP*	no	4.6	1.2	1.7	3.1	.8	11.4

AVERAGE AIR-SEA CRAFT INITIAL INVESTMENT COST

Air-Sea Craft Configuration	Less Payload	With Payload
S/CTOL	14.2	16.0
SR/VTOL	62.6	64.4

Payload	Payload Cost
Retrievable Buoys	1.5
Weapons, Expendable Buoys, Markers	0.3
Total	1.8

NA not applicable

* no sea legs, boundary layer control or hydroski systems

3.0 OPERATING COSTS

Operating costs are developed on an annual and cost/sortie basis. The cost/sortie rather than cost/flying hour is selected as a cost measure for air-sea craft comparison. The cost/flying hour factor is somewhat unrealistic because of the extended time the air-sea craft are seaborne in the performance of their missions.

Factors considered in the operating costs are:

1. Air-sea craft utilization
2. Fuel costs
3. Overhaul and maintenance costs
4. Personnel costs
5. Base costs

3.1 Air-Sea Craft Utilization

The assumed single air-sea craft utilization for each of the ONR mission profiles is shown in Table 27.

TABLE 27

ANNUAL SINGLE AIR-SEA CRAFT UTILIZATION

ONR Mission Profile No.	Mission Endurance	No. of Sorties/Yr	No. of Fly Hrs/Yr
1	10 Hrs	120	720
1A	10	120	720
2	15	96	960
3	30	72	1008
4	60	72	1008

3.2 Air-Sea Craft Fuel Costs

The air-sea craft use 90% of their fuel during a single sortie; fuel cost is assumed to be \$.02/lb. The annual fuel cost for each air-sea craft is based on the number of sorties listed in Table 27.

3.3 Overhaul and Maintenance Costs

These costs are computed by the method developed in Ref. 2. Overhaul and maintenance costs are based on an aircraft system life of 7 years. Overhaul schedule is as follows:

1. Airframe: twice during expected system life.
2. Avionics, electronics, and retrievable sonobuoys: once each year
3. Propulsion: 600 hours between engine overhauls.

Cost factors employed are:

		$ Labor		$ Materiel
1.	Airframe (A/F)	$\frac{2 \times \text{lbs A/F} \times \$2.44}{7 \text{ yrs}}$	+	$\frac{.06 \times \$ \text{ A/F}}{7 \text{ yrs}}$
2.	Avionics, Electronics, and Retrievable Sonobuoys (AES)	$\frac{\text{lbs (AES)} \times \$7.00}{7 \text{ yrs}}$	+	$\frac{.20 \$ \text{ (AES)}}{7 \text{ yrs}}$
3.	Propulsion (P)	$\frac{\text{Fly. Hrs.} \times \$.60 \times \text{HP}}{600 \text{ (TBO)*}}$	+	$\frac{.45 \$ \text{ P}}{7 \text{ yrs}}$

3.4 Personnel Costs

Personnel costs are derived from the average peacetime/wartime personnel allowance per aircraft given in Reference 3. The number of assigned personnel are plotted vs aircraft operating weight empty (Figure 19). A straight line is fitted by the least square method. This relationship, which is expressed by the equation

No. of Personnel = 8.5 + .00057 air-sea craft operating weight empty (OWE)

is used to estimate the number of personnel associated with each of the candidate air-sea craft. Personnel costs are computed by applying the average Navy personnel cost of $4600/Yr given in Ref. 1.

* Hours flying time between overhauls.

3.5 Base Costs

The candidate air-sea craft are assumed to be normally shore-based. The only pertinent data available concerning the yearly cost of a base installation is contained in Reference 3 for P3V-1 aircraft. This reference shows an average yearly base cost of \$190,000 per aircraft. In the absence of additional information, the following relationship is used for allocating base costs to each candidate air-sea craft:

$$\text{Estimated annual base cost} = \frac{\text{Operating weight empty of candidate air-sea craft}}{\text{Operating weight empty of P3V-1}} \times \$190,000$$

3.6 Annual Operating Costs and Costs/Sortie

Estimated annual operating costs and costs/sortie, based on the above cost categories are listed in Table 28. The cost/sortie is merely the annual operating cost divided by the assumed number of annual sorties listed in Table 27.

The operating costs exhibit the same trends as the initial investment costs. The smaller aircraft, e.g., those without sealegs and with RTP engines, have lower operating costs than comparable aircraft with sealegs and TP engines. The SR/VTOL aircraft exhibit the highest operating costs and costs/sortie.

4.0 ADDITIONAL OPERATING COST FACTORS

In evaluating the total mission cost of an air-sea craft system in a given mission, several other operations must be costed. These include:

1. Carrier basing (mission profile 1A only)
2. Air-sea craft refueling
3. Loss of retrievable sensors
4. Weapon expenditure

These costs are developed as follows.

TABLE 28

ESTIMATED ANNUAL OPERATING AND SORTIE COSTS PER AIR-SEA CRAFT
COSTS IN $ THOUSANDS

A/C CONFIG.	TYPE ENGINE	SEA LEGS	ONR Mission Profile 1A		2		3		4	
			*	**	*	**	*	**	*	**
CTOL	TP	Yes	240	2	750	8	1010	14	1450	20
STOL	TP	Yes	270	2	780	8	1060	15	1530	21
CTOL	RTP	Yes	230	2	520	5	660	9	860	12
STOL	RTP	Yes	240	2	550	6	700	10	900	13
CTOL	CF	Yes	230	2	530	6	680	9	880	12
SR/VTOL	RTP	Yes	280	2	980	10	1660	23	2880	40
VTOL	RTP	Yes	320	3	NA		NA		NA	
CTOL	TP	No	220	2	560	6	740	10	980	14
STOL	TP	No	230	2	580	6	780	11	1020	14
CTOL	RTP	No	200	2	420	4	540	8	780	11
STOL	RTP	No	210	2	440	5	570	8	720	10
CTOL	CF	No	210	2	430	4	560	8	700	10
CTOL[1]	TP	No	200	2	490	5	640	9	830	12
AVG S/CTOL			230	2	550	6	720	10	960	13
SR/VTOL			300	3	980	10	1660	23	2880	40

[1] without sealegs, hydroski or boundary layer control systems
NA not applicable
*$/year
**$/sortie

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4.1 Carrier Basing

In certain missions (barrier, and task group and convoy screening) it is necessary to base mission profile 1A aircraft on carrier-type surface ships. The cost of basing a given number of air-sea craft aboard a particular aircraft carrier for the duration of the mission is derived to be:

$$\text{Basing Cost} = \frac{N_{A/C} \cdot DS_{A/C}}{DS_{CV}} \times \frac{T_M}{1\ \text{Yr.}} \times OC_{CV}$$

where $N_{A/C}$ = number of aircraft required in the mission

$DS_{A/C}$ = deck space required by given air-sea craft

DS_{CV} = total carrier deck space

T_M = mission duration

OC_{CV} = annual operating cost of the carrier

The first term in the expression represents the number of carriers required of a given type to supply the deck space for $N_{A/C}$ air-sea craft, each of which requires $DS_{A/C}$ deck space. Note that the first term given above yields fractional numbers of carriers required; if integral numbers of carriers are desired, the first term would be the next integer larger than the fractional number shown.

Numerical values for the parameters are obtained from Navy sources:

$N_{A/C}$ = a function of the mission

$DS_{A/C}$ = deck space required by a 1A air-sea craft is assumed to be equal to that of an A3J aircraft, which is approximately 2325 sq.ft. (References 5, 6).

DS_{CV} = a function of the aircraft carrier used. Deck spaces of typical carriers are (Reference 7):

CVA 19	82,000 sq.ft
CVA 41	104,000 sq.ft
CVA 59	146,000 sq.ft

The CVA 19 is selected for this function because the smallest CVA in the present Navy task group is most likely to be used as an antisubmarine carrier in the 1973-1980 time period. Therefore DS_{CV} = 82,000 ft.

T_M = a function of the mission. In barrier operations a uniform mission duration of 2000 hours is used; in task group and convoy screening, a travel distance of 1000 n.mi. is used at speeds of 8, 15 and 26 knots. Hence the mission times in the latter mission are 125, 66.7, and 38.4 hours, respectively.

OC_{CV} = \$11.78 x 10^6 per yr. for the CVA 19 (Reference 1)

The initial formula can now be expressed in numerical terms:

$$\text{BASING COST} = \frac{N_{A/C} \cdot 2325}{82,000} \times \frac{T_M}{1 \text{ yr}} \times \$11.78 \times 10^6$$

$$\text{BASING COST} = 0.333963 \frac{T_M}{1 \text{ yr.}} \quad N_{AC} \times \$10^6$$

For Barrier Mission $\frac{T_M}{1 \text{ yr.}} = \frac{2000}{8760} = 0.2283$

$$\text{Basing Cost} = 0.07624\ N_{A/C} \times \$10^6$$

For Task Group and Convoy Screening Missions

$$\frac{T_M}{1 \text{ yr.}} \text{ at } 8\text{ k} = \frac{125}{8760} = 0.01426$$

$$\frac{T_M}{1 \text{ yr.}} \text{ at } 15\text{ k} = \frac{66.7}{8760} = 0.007614$$

$$\frac{T_M}{1 \text{ yr.}} \text{ at } 26\text{ k} = \frac{38.4}{8760} = 0.004383$$

Therefore

$$\text{Basing Cost (8 k)} = 0.004762\ N_{A/C} \times \$10^6$$

$$\text{Basing Cost (15 k)} = 0.002543\ N_{A/C} \times \$10^6$$

$$\text{Basing Cost (26 k)} = 0.001464\ N_{A/C} \times \$10^6$$

4.2 Air-Sea Craft Refueling

In task group screening missions, refueling of the air-sea craft is necessary in sea-based systems. The cost of refueling a given number of air-sea craft from a given tanker for the duration of the mission is found to be:

$$\text{Refueling Cost} = \frac{N_S \cdot F_{L(A/C)}}{F_{L(Tanker)}} \times \frac{T_M}{1 \text{ yr.}} \times OC_{Tanker}$$

where N_S = number of air-sea craft sorties in the mission *

$F_{L(A/C)}$ = fuel load of one air-sea craft

$F_{L(Tanker)}$ = fuel load of tanker

T_M = mission duration

OC_{Tanker} = annual operating cost of the tanker

The first term in the expression represents the number of tankers required of a given type to supply the fuel for N_S sorties by air-sea craft each of which requires $F_{L(A/C)}$ fuel. Fractional numbers of tankers are used in the analysis.

Numerical values for the parameters are obtained from Navy sources:

N_S = a function of the mission

$F_{L(A/C)}$ = varies with the type of air-sea craft.

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* The air-sea craft is assumed to have finished a sortie when refueling is necessary.

FUEL LOAD (LBS.)

MISSION PROFILE	S/CTOL	SR/VTOL
1	3940	3760
1A	5300	5720
2	28800	60400
3	44000	117200
4	62400	223800

$F_{L(Tanker)}$ = a function of the tanker selected:

TANKER CHARACTERISTICS*

TYPE	DISPLACEMENT (Tons)	FUEL LOAD lbs.	OP. COST/YR $\$10^6$ (Reference 1)
AOE	51,000	9,962,000	3.33**
AO	38,000	7,015,870	1.96
AO	24,830	9,191,360	1.96
AOG	4,330	4,853,907	0.625

* Reference 6

** Estimated on the basis of cost-per-ton displacement of the AO tankers

The AOE tanker, being the largest of the group, is selected for use in the study.

T_M = A function of the mission. A constant task group and convoy screening distance of 1000 n.mi. is covered at 8, 15, and 26 knots. The mission times are thus 125, 66.7, and 38.4 hrs. respectively.

$$OC_{Tanker} = \$3.33 \times 10^6 \text{ per yr. for the AOE tanker}$$

The initial formula c ..ow be expressed in numerical terms.

$$\text{Refueling Cost} = \frac{N_S \cdot F_{L(A/C)}}{9,962,000} \times \frac{T_M}{1 \text{ yr.}} \times \$3.33 \times 10^6$$

$$\frac{T_M}{1 \text{ Yr.}} \text{ at } 8\text{ k} = 0.01426$$

$$\frac{T_M}{1 \text{ Yr.}} \text{ at } 15\text{ k} = 0.007614$$

$$\frac{T_M}{1 \text{ Yr.}} \text{ at } 26\text{ k} = 0.004383$$

Since $F_{L(A/C)}$ varies with the mission profile and type of air-sea craft, it is convenient to make a table of the following form:

MISSION PROFILE	A/C TYPE	FUEL LOAD (lbs.)	REFUELING 8K	COST 15K	FACTOR 26K
1	S/CTOL	3940	18.78	10.03	5.77
	SR/VTOL	3760	17.92	9.57	5.51
1A	S/CTOL	5300	25.27	13.49	7.76
	SR/VTOL	5720	27.27	14.56	8.38
2	S/CTOL	28800	137.29	73.30	42.19
	SR/VTOL	60400	287.93	153.72	88.49
3	S/CTOL	44000	209.75	111.98	64.46
	SR/VTOL	117200	558.69	298.27	171.70
4	S/CTOL	62400	297.46	158.81	91.42
	SR/VTOL	223800	1066.85	569.57	327.87

The above refueling cost factors are to be multiplied by the number of sorties N_S and divided by 10^6 to obtain the refueling cost in 10^6 dollars.

4.3 Loss of Retrievable Buoys

In missions where passive or active ATSSS-type retrievable buoys are employed, a certain percentage of the buoys will likely be lost. The total loss is then a function of the loss rate, the total weight of buoys emplaced in the water, and the average cost of the buoys per pound. The cost of the buoy loss is then given by

$$\text{Loss of Buoy Cost} = L_R \cdot W_E \cdot C_B$$

where L_R = the buoy loss rate

W_E = the total buoy weight emplaced

C_B = the average buoy cost per pound

Numerical values are as follows:

L_R = about 3% (reported in ATSSS references in Part II of Volume IV of this report on acoustic sensor characteristics.)

W_E = a function of the number of buoys emplaced in a mission. Single buoy weights used in the analysis are:

passive		
	light	1000 lbs
	heavy	1800 lbs
active		3500 lbs

C_B = estimated at $50 per pound.

4.4 Weapon Expenditure

In each of the ASW missions examined, all contacts are investigated and (except for the trailing mission) attacked if classified as enemy submarines. The cost of such attacks is derived as:

$$\text{Weapon Expenditure Cost} = N_C \cdot \frac{T_M}{1 \text{ yr}} \cdot N_A \cdot N_W \cdot C_W$$

where N_C = number of contacts in a given time period

T_M = mission duration

N_A = number of attacks made per contact

N_W = number of weapons expended per attack

C_W = cost of a single weapon

Numerical values used for these parameters are as follows:

N_C = varied parametrically with the mission. In barriers, contact rates used are:

Mode E System:	1 contact per sortie
Mode C, D Systems:	0, 2, 6 and 18 contacts per day over the barrier
Mode A, B Systems:	18 contacts per day over the barrier

No contact rates are used in screening, contact area investigation, and trailing missions.

T_M = a function of the mission. Discussed previously.

N_A = assumed to be 1 attack per contact

N_W = two MK 46 torpedoes are expended in each attack

C_W = the cost of a single MK 46 torpedo, which is about $50,000 in lots of 1000 (Reference 3). To this must be added the cost of expendable sonobuoys used for localization. A maximum number per attack is estimated at 20 and the total sonobuoy cost (at an estimated $750 per buoy) is $15,000. Thus the cost per attack by 2 MK 46 torpedoes and using 20 sonobuoys is $115,000.

Expressing the initial formula in numerical terms,

$$\text{Weapon Expenditure Cost} = \underset{\text{(per day)}}{N_C} \times \frac{2000\ \text{hrs.}}{24\ \text{hrs.}} \times 1 \times 0.115 \times \$10^6$$

$$\text{Weapon Expenditure Cost} = 9.5833\ N_{C/DAY} \times \$10^6$$

There is a requirement which must be satisfied in air-sea craft attacks: the number of weapons available on the air-sea craft in operation must be equal to or greater than the number of weapons required to attack each contact. That is,

$$N_{\substack{\text{WEAPONS}\\ \text{AVAILABLE}}} \geqq 2\ N_{\text{ATTACKS}}$$

$$N_{\substack{\text{TOTAL SORTIES}\\ \text{IN MISSION}}} \times N_{\substack{\text{WEAPONS}\\ \text{PER A/C}}} \geqq 2\ N_{\substack{\text{CONTACTS}\\ \text{PER DAY}}} \times \frac{2000\ \text{Hrs}}{24\ \text{Hrs.}}$$

Therefore the number of contacts per day which can be attacked using the available weapons is

$$N_{\substack{\text{CONTACTS}\\ \text{PER DAY}}} \leqq 0.006\ N_{\text{SORTIES}}\ N_{\substack{\text{WEAPONS}\\ \text{PER A/C}}}$$

The number of weapons varies with the mission profile air-sea craft; therefore we have

MISSION PROFILE	N_W	
1A and 2	2	$N_{\text{CONTACTS/DAY}} \leqq 0.012\ N_{\text{SORTIES}}$
3 and 4	4	$N_{\text{CONTACTS/DAY}} \leqq 0.024\ N_{\text{SORTIES}}$

The number of contacts per day which can be attacked using the weapons available on the air-sea craft deployed may be compared with the number of contacts per day assigned to the study: 0, 2, 6, and 18. This comparison is made for the barrier mission in Tables 29, 30, and 31 below.

The comparison in these tables of the assigned contact rate per day with the maximum number of contacts/day which can be attacked shows that:

1. No mission profile air-sea craft can carry out attacks on 18 contacts per day.
2. Only the 1A mission profile air-sea craft can carry out attacks on 6 contacts per day.
3. All mission profile air-sea craft can carry out attacks on 0 or 2 contacts per day.

It is clear that not all the contact rates assigned can be attacked by all mission profile air-sea craft employed in all barrier modes. For this reason, the cost of expendable weapons is not included in the cost analysis at the present time. Further analysis of barrier operations to include attack capability designed to accommodate the contact rates assigned would be necessary before weapon expenditure cost could be included in the system cost-effectiveness.

It may be pointed out that in those cases above in which the assigned number of contacts per day can be attacked by all air-sea craft in all barrier modes (0 and 2 contacts per day), the increase in total mission cost is substantial. For example, a mission profile 4 SR/VTOL air-sea craft in a barrier mode C operation could attack 2 contacts/day for an increase in total mission cost of 343 percent.

The results shown in Tables 29, 30, and 31 are based upon nonnuclear torpedo attacks. It is seen that the mission profile 1A air-sea craft is able to make more attacks than the 2, 3, or 4 air-sea craft. There are two reasons for this: (1) greater numbers of 1A air-sea craft are employed than of the other air-sea craft, and (2) the entire weapon load of the 1A air-sea craft

(2 torpedoes) can be used in nonnuclear attacks. The entire weapon loads of the other air-sea craft cannot be used in nonnuclear attacks, however, because part of their weapon load consists of nuclear depth bounds. (See Table 2 for air-sea craft weapon loads). To compare the attack capabilities of the air-sea craft in a nonnuclear situation, the nuclear depth bomb portions of the weapon loads of mission profiles 2, 3, and 4 should be replaced by nonnuclear torpedoes. If this is done, the numbers of torpedoes carried by the air-sea craft are increased as follows: mission profile 2: 2 torpedoes to 4; 3: 4 torpedoes to 6; and 4: 4 torpedoes to 8. The resultant numbers of contacts which can be attacked are then increased as shown by the numbers in parentheses in Tables 29, 30, and 31. Assuming all-torpedo weapon loads for the air-sea craft, it is seen that:

1. No mission profile air-sea craft can carry out attacks on 18 contacts per day.

2. All mission profile air-sea craft can carry out attacks on 0, 2, or 6 contacts per day.

Thus, even if the air-sea craft carried all-torpedo weapon loads, not all the contact rates assigned can be attacked with the available weapons.

TABLE 29

MAXIMUM NUMBER OF CONTACTS PER DAY WHICH CAN BE ATTACKED

(18 Contacts Per Day Assigned)

BARRIER MODE*	ASSIGNED NO. OF CONTACTS/DAY	MISSION PROFILE	NO. OF SORTIES PER 2000 HRS.	MAXIMUM NO. OF CONTACTS/DAY WHICH CAN BE ATTACKED	
A	18	1A	856	10.3	(10.3)
		2	444	5.3	(10.6)
		3	243	5.8	(8.7)
		4	243	5.8	(11.6)
B	18	1A	856	10.3	(10.3)
		2	444	5.3	(10.6)
		3	243	5.8	(8.7)
		4	170	4.1	(8.2)
C	18	1A	1175	14.1	(14.1)
		2	516	6.2	(12.4)
		3	387	9.3	(14.0)
		4	387	9.3	(18.6)
D	18	1A	1109	13.3	(13.3)
		2	448	5.4	(10.8)
		3	294	7.1	(10.7)
		4	277	6.6	(13.2)

*Barrier Modes:
A Waterborne Monitoring: Minimum No. of Air-Sea Craft
B Waterborne Monitoring: Minimum No. of Sorties
C Airborne Monitoring: Minimum No. of Air-Sea Craft
D Airborne Monitoring: Minimum No. of Sorties

( ) Results assuming all-torpedo weapon loads on all mission profile air-sea craft

TABLE 30

MAXIMUM NUMBER OF CONTACTS PER DAY WHICH CAN BE ATTACKED

(6 Contacts Per Day Assigned)

BARRIER MODE	ASSIGNED NO. OF CONTACTS/DAY	MISSION PROFILE	NO. OF SORTIES PER 2000 HRS.	MAXIMUM NO. OF CONTACTS/ DAY WHICH CAN BE ATTACKED	
A	6	1A			
		2	Not Analyzed		
		3			
		4			
B	6	1A			
		2	Not Analyzed		
		3			
		4			
C	6	1A	696	8.3	(8.3)
		2	244	2.9	(5.8)
		3	220	5.2	(7.8)
		4	220	5.2	(10.4)
D	6	1A	696	8.3	(8.3)
		2	294	3.5	(7.0)
		3	197	4.7	(7.0)
		4	173	4.2	(8.4)

( ) Results assuming all-torpedo weapon loads on all mission profile air-sea craft

TABLE 31

MAXIMUM NUMBER OF CONTACTS PER DAY WHICH CAN BE ATTACKED

(2 Contacts Per Day Assigned)

BARRIER MODE	ASSIGNED NO. OF CONTACTS/DAY	MISSION PROFILE	NO. OF SORTIES PER 2000 HRS.	MAXIMUM NO. OF CONTACTS/ DAY WHICH CAN BE ATTACKED	
A	2	1A	Not Analyzed		
		2			
		3			
		4			
B	2	1A	Not Analyzed		
		2			
		3			
		4			
C	2	1A	598	7.2	(7.2)
		2	220	2.6	(5.2)
		3	166	4.0	(6.0)
		4	166	4.0	(8.0)
D	2	1A	585	7.0	(7.2)
		2	220	2.6	(5.2)
		3	150	3.6	(4.8)
		4	150	3.6	(7.2)

( ) Results assuming all-torpedo weapon loads on all mission profile air-sea craft

5.0 COSTS EMPLOYED IN COST EFFECTIVENESS EVALUATION

The costs employed for the subsequent cost effectiveness evaluation in Volume VI of the candidate air-sea craft are summarized in Table 32.

To determine the initial investment cost of an ONR Mission Profile 1A S/CTOL, a production quantity of 500 air-sea craft is assumed. From Figure 18, this amounts to a total cost of $\$1,350 \times 10^6$ or an average air-sea craft cost of $\$2.7 \times 10^6$. Again using Figure 18, the total number of air-sea craft which could be produced for the same total expenditure is determined for the other types of air-sea craft and associated ONR mission profiles and the average initial investment costs computed.

The payload costs listed in Tables 23 through 26 are added to the above costs and the resultant costs are used as the initial investment costs in the cost-effectiveness comparisons.

Annual operating costs and costs per sortie are the average S/CTOL and SR/VTOL costs listed at the bottom of Table 28 for the four ONR mission profiles. The lifetime cost is defined as the initial investment cost + 7 x the annual operating cost.

TABLE 32

COSTS EMPLOYED IN COST-EFFECTIVENESS EVALUATION

COST IN $ MILLIONS

Air-Sea Craft Type	ONR Mission Profile	No. of Air-Sea Craft	Initial Investment Cost with Payload	Annual Operating Cost	Lifetime Cost	Sortie Cost
S/CTOL	1A	500	3.1	.230	4.7	.002
SR/VTOL	1A	265	5.5	.300	7.6	.003
S/CTOL	2	200	7.9	.550	11.8	.006
SR/VTOL	2	55	25.6	.980	32.5	.010
S/CTOL	3	125	12.2	.720	17.2	.010
SR/VTOL	3	23	60.1	1.660	71.7	.023
S/CTOL	4	94	16.2	.960	22.9	.013
SR/VTOL	4	11	124.5	2.880	144.7	.040

Note: Operating and lifetime costs do not include loss of electronic equipment and weapons expended.

6.0 REFERENCES

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